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COVER: *Bombus vosnesenskii* (Hymenoptera: Apidae)

The yellow-faced bumble bee, *Bombus vosnesenskii*, is found across large areas of western North America. Like many other native pollinators in North America, it faces threats due to habitat loss and pesticide usage. However, unlike many other native bumblebees, its range seems to be currently expanding in some areas. On page 31 of this issue of the *Journal of the Entomological Society of British Columbia*, David F. Fraser and his co-authors document this species' range expansion in southern British Columbia.

The news is not all good. The expansion of the yellow-faced bumblebee may be occurring due to declines in populations of the western bumble bee, *Bombus occidentalis*.

Photograph details:

Sean McCann photographed this yellow-faced bumble bee worker foraging on *Echinacea purpurea* growing in a local community garden in Pandora Park, Vancouver, British Columbia. The flowers planted there attract many insects that would not ordinarily be abundant in the area. Technical details: Canon 60D; f/11; 100 mm; ISO 200; lit with two diffused off-camera flashes.

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Directors of the Entomological Society of British Columbia, 2012-2013.....	2
J.J. Holland. 'Cosmetic' Pesticides: Safe to Use by Professionals and Homeowners.....	3
G.E. Haas, J.R. Kucera, S.O. MacDonald, and J.A. Cook. First flea (Siphonaptera) records for Kanuti National Wildlife Refuge, Central Alaska.....	6
S. Acheampong, D.R. Gillespie, and D.J.M. Quiring. Survey of parasitoids and hyperparasitoids (Hymenoptera) of the green peach aphid, <i>Myzus persicae</i> and the foxglove aphid, <i>Aulacorthum solani</i> (Hemiptera: Aphididae) in British Columbia.....	12
J.W. Miskelly. Updated checklist of the Orthoptera of British Columbia.....	24
D.F. Fraser C.R. Copley, E. Elle, and R.A. Cannings. Changes in the Status and Distribution of the Yellow-faced Bumble Bee (<i>Bombus vosnesenskii</i>) in British Columbia	31
David R. Horton, Christelle Guédot, and Peter J. Landolt. Identification of feeding stimulants for Pacific coast wireworm by use of a filter paper assay (Coleoptera: Elateridae).....	38
Brittany E. Chubb, Caroline M. Whitehouse, Gary J. R. Judd, Maya L. Evenden. Success of <i>Grapholita molesta</i> (Busck) reared on the diet used for <i>Cydia pomonella</i> L. (Lepidoptera: Tortricidae) sterile insect release	48
G. G. E. Scudder. Additional provincial and state records for Heteroptera (Hemitera) in Canada and the United States	55
SCIENTIFIC NOTES	
A.G. Wheeler, JR. and E. Richard Hoebeke. <i>Metopoplax ditomoides</i> (Costa) (Hemiptera: Lygaeoidae: Oxycarenidae): First Canadian Record of a Palearctic Seed Bug.....	57
B. Staffan Lingren, Daniel R. Miller, J. P. LaFontaine. MCOL, frontalinal and ethanol: A potential operational trap lure for Douglas-fir beetle in British Columbia.....	59
ANNUAL GENERAL MEETING ABSTRACTS	
Entomological Society of British Columbia Annual General Meeting Symposium Abstracts: Grape IPM	74
Entomological Society of British Columbia Annual General Meeting Presentation Abstracts...	76
NOTICE TO CONTRIBUTORS	Inside Back Cover

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FORUM

‘Cosmetic’ Pesticides: Safe to Use by Professionals and Homeowners**JOHN J. HOLLAND¹**

The Special Committee on Cosmetic Pesticides was instituted by the British Columbia government to investigate whether or not pesticides can be used safely for the protection of ornamental plants and turf. After hosting numerous presentations in order to gain a fundamental understanding of the issue, the Committee recently concluded that there existed no scientific grounds to prohibit the products (Bennett, 2012). Representatives of Health Canada’s Pest Management Regulatory Agency (PMRA), the agency responsible for ensuring the safety of pesticides, appeared twice and also provided written responses to two submitted lists of questions. Dr. Keith Solomon, one of Canada’s most internationally respected toxicologists and acclaimed expert on pesticides, answered committee questions by conference call.

Many presenters were opposed to the use of pesticides. Unfortunately, none of them had a background in toxicology or the necessary expertise in pesticide science. The Canadian Cancer Society, one of the organizations most vocal in opposing pesticides, presented on November 8, 2011, with Kathryn Seely (CCS Public Issues Manager) stating that the Society had “weighed the growing body of evidence that’s suggestive.” But therein lays the problem: the CCS seems to regard as trustworthy only selected and weak epidemiological studies that fit preconceived notions concerning the ‘dangers’ of pesticides. The Society has managed to collect 200 or so selected epidemiological studies with weak correlations; but compare these to the 23,000,000 pages of proprietary scientific studies alone which the PMRA uses to assess pesticide safety (as explained by the PMRA’s Jason Flint – Director, Policy and Regulatory Affairs Division – in the January 17, 2012 presentation to the committee). Also not understood by many Canadians is that the

CCS is a fund-raising advocacy association, not a scientific organization.

A tenet of epidemiology is that correlations cannot prove causation. As well, epidemiology cannot prove biological plausibility. Toxicological confirmation is required in order to illustrate plausibility, and none exists to substantiate the suggestion that ‘cosmetic’ pesticides cause cancer. Furthermore, no ‘cosmetic’ pesticide registered in Canada today has been determined to be carcinogenic by any regulatory agency in the world. The CCS, which has done much good work in the past, would seem to have lost its way on this issue, perhaps preferring to follow opinion rather than science.

In response to a written question submitted by the Committee on April 30, 2012, the PMRA stated that “(w)hen determining the acceptability of a pesticide, PMRA scientists critically examine the totality of the scientific database for pesticide active ingredients and end-use products, including the epidemiological studies in the OCFP (Ontario College of Family Physicians).” This could certainly help explain the difference between the conflicting stances of the PMRA and the CCS: the PMRA considers all the evidence, including toxicology, not just a few selected epidemiological studies.

In 2007, a report by the World Cancer Research Fund International and the American Institute for Cancer Research outlined the results of a five-year review by nine teams of international cancer experts. One of the main findings is as follows: “There was no epidemiological evidence that current exposures to pesticides cause cancer in humans” (WCRFI and the AICR, 2007). The same report maintains that it is necessary to enroll 10,000 to 100,000 or more subjects in a study, in order “to have sufficient statistical power to identify factors that may increase cancer by as little as 20 to 30 per cent.” The

¹Communications Director, Integrated Environmental Plant Management Association of Western Canada

studies promoted by the CCS and other anti-pesticide organizations generally have considerably less than 2,000 subjects enrolled. Because epidemiological correlations are based on statistics, many subjects are required to provide some assurance that links are not merely chance occurrences.

The ongoing American Health Study (AHS) was initiated in 1994 and is the largest continuous epidemiological study ever undertaken on the possible effects of pesticides. It has 89,000 Iowa and North Carolina farmers, spouses, and commercial applicators enrolled, in order to examine possible causes of diseases – including cancer. In a review of the findings of the AHS, the PMRA's Dr. Scott Weichenthal stated at a 2009 Health Canada meeting in Winnipeg that "current occupational exposure levels are not expected to result in increased risks of adverse health effects." If occupational exposures to pesticides were not creating adverse health effects, why would homeowners and others with extremely limited exposure to pesticides develop them?

As another of its stated reasons for a prohibition, the CCS says that the International Agency for Research on Cancer (IARC) finds that pesticides can be carcinogenic. What is not mentioned, however, is that none of the recognized carcinogenic pesticides are registered for use in Canada. And, according to a recent report by the IARC, "(v)ery few currently available pesticides are established experimental carcinogens, and none is an established human carcinogen. Studies in humans have failed to provide convincing evidence of an increased risk, even in heavily exposed groups" (IARC, 2007). In the words of Dr. Connie Moase (Director, PMRA Health Evaluation Directorate) in her appearance before the Committee on January 17, 2012:

For any known human carcinogen, whatever the chemical might be – I'm not speaking directly to pesticides – the animal models that have been used have shown to be positive for anything that's known

to be carcinogenic to humans as well. So they are well understood predictors of potential human toxicity, and those are the models that are well worked out and used for toxicity testing.

Some medical associations have joined with the CCS to oppose pesticides. Unfortunately, physicians generally have neither the scientific nor toxicological expertise that must be gained over years of postgraduate studies and experience, and the position of a medical association's board of directors does not necessarily represent that of the majority of its members.

The 'viable' organic alternatives, suggested by those opposed to conventional products, are much more expensive, very labour-intensive, and do not work very well – if at all. As Health Canada states, "(i)n most cases, efficacy data requirements for non-conventional products will be less than for conventional pest control products and the establishment of a lowest effective rate (such as is required for conventional products) will not be needed. The PMRA recognizes that some non-conventional products may not be as efficacious as conventional products" (Health Canada, undated).

A ban of 'cosmetic' pesticides in B.C. would result in a duplication of Ontario's experience: parks so full of weeds that they cannot be used, lawns destroyed by grubs, and ornamentals lost to insects and disease. The next time you hear of a study about the 'danger' of pesticides, you should ask the following two questions: (1) is the study epidemiological and, if so, how many subjects were enrolled?; and (2) does toxicology confirm the biological plausibility of the suggested correlation?

Removing useful products that can be used safely – merely because weak epidemiological studies are proffered as evidence (without toxicological findings to substantiate correlations) – is not part of a scientific process. Fortunately, the Special Committee on Cosmetic Pesticides made a decision based on science, not opinion.

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Disclaimer

The BC Cancer Agency was also asked to write a Forum article on the topic of cosmetic pesticides. We hope to run their contribution to this discussion in an upcoming ESBC publication.

JESBC Forum articles express the opinion of the author(s) and do not necessarily reflect the views of the Entomological Society of British Columbia. Forum pieces are presented to stimulate discussion on matters related to entomological research and practice, and we invite potential authors to contact us with ideas for future Forum articles.

First flea (Siphonaptera) records for Kanuti National Wildlife Refuge, Central Alaska.

GLENN E. HAAS¹, JAMES R. KUCERA², S. O. MacDONALD³ and JOSEPH A. COOK³

ABSTRACT

Kanuti National Wildlife Refuge (KNWR) was established in 1980 in Central Alaska. Collections of mammal fleas began in 1991. Six species resulted: *Catallagia dacenkoi* Ioff, *Corrodopsylla curvata* (Rothschild), *Ctenophthalmus pseudagyrtes* Baker, *Megabothris calcarifer* (Wagner), *Amalaraeus dissimilis* (Jordan) and *Peromyscopsylla ostsibirica* (Scalon). Ten species of fleas were previously recorded from the upper Koyukuk River watershed. One female specimen each of *C. curvata* and *Ct. pseudagyrtes* from the KNWR are the only new fleas added to the upper watershed list.

Key Words: fleas, Siphonaptera, mammal hosts, Alaska

INTRODUCTION

The upper Koyukuk River watershed in Central Alaska (MacDonald and Cook 2009: Figs. 10, 12, pp. 33, 34) was mostly an unknown Arctic wilderness before 1929 (Figure 1). The earliest systematic comprehensive mapping survey of the topography of this large area from the Brooks Range south to the Arctic Circle was accomplished from 1929 to 1939 primarily by R. Marshall (1956: maps pp. 6, 34, 35, 111, 143 + folding map). Flea collections begun in 1955 were facilitated by accurate detailed maps showing rivers, lakes and villages.

Recent collections in Kanuti NWR since 1991 benefitted from instruments for determining georeferenced locality coordinates.

The length of KNWR north of the Arctic Circle is ca. 35 km and ca. 63 km south of it. The south portion extends from 66°33' to slightly more than 1 km south of 66°00'. Collections by Patsy Martin are nearest the Arctic Circle at 66°19'9", i.e., 13'51" south of 66°33'. Marshall's maps only extend ca. 10 km south of the Arctic Circle. Thus, they could not be used to confirm KNWR localities.

MATERIALS AND METHODS

Collecting began in KNWR on 9 September 1991 when Patsy Martin recorded AF1115 (UAM22104) ex *Myodes* (formerly *Clethrionomys*) *rutilus* near small lakes south of the Arctic Circle at 66°19'0"N, 151°47'0"W. On 10 and 11 September 1991 8 additional AF records had *Sorex cinereus* Kerr (1), *Synaptomys borealis* (Richardson) (1), and *Microtus pennsylvanicus* (2) as well as *My. rutilus* (4). We have not seen the fleas in these 9 collections nor in AF1644 (UAM46647) recorded by Aliy Zirkle on 27 August 1993, south of the Arctic Circle at

66°18'12"N, 151°46'30"W. Most flea specimens that we obtained had complete field collection data that facilitated identifications. Field collection years were 1991 (fleas not seen), 1992, 1993, 1996 and 2006. Patsy Martin was the most active collector. Other contributors were A. Zirkle, J. Bopp, and R. Brubaker. More recently, specimens (2006) were collected by L. Saperstein. Her new collections are welcome compensation for fleas missing in 1991 and 1993 (see below). All localities were south of the Arctic Circle. Six species of fleas from 7 species of

¹ Dr. Glenn Haas died during the publication of this work. Glenn was a long-time supporter of the Society and made major contributions to the knowledge of western North American Siphonaptera. He will be missed.

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mammalian hosts from KNWR were studied. Note that we received a report that whatever fleas were collected by Martin in 1991 and Zirkle in 1993 were transferred from the Nixon Wilson collection to the University of Nebraska, Lincoln collection for curation in 2012.

Acronyms identifying collectors of flea specimens mainly in the species accounts are as follows: AZ=Aliy Zirkle; JB=Jesse Bopp; PM & PAM=Patsy Martin; RB=Rachel Brubaker; LS=Lisa Saperstein.

After receiving one or more fleas in a vial of 70% ethanol containing an AF label matching the AF for the mammal host on data provided by University of Alaska, Fairbanks, all specimens were permanently slide-mounted in Canada balsam. Technique for slide-mounting is as specified in Haas *et al.*, 2005.

KANUTI NWR SPECIES ACCOUNTS CTENOPHTHALMIDAE

Catallagia dacenkoi Ioff, 1940

Material examined: USA: AK: 66°19.4'N, 151°46.9'W, 1♂ from *Microtus oeconomus* [AF1585; UAM47004], 28.viii.1993, AZ. 66°18'43"N, 151°46'32"W, 1♂, 1♀ from *M.*

oeconomus [AF18469; UAM38386], 9.viii.1996, PM. 66°18'45"N, 151°45'59"W, 1♀ from *Microtus pennsylvanicus* [AF18466; UAM41561], 8.viii.1996, PM. 66°19'9"N, 151°47'41"W, 1♂, 1♀ from *Myodes rutilus* [AF18454; UAM38338], 1.ix.1996, PM. 66°19'9"N, 151°47'41"W, 1♀ from *M. rutilus* [AF18450; UAM38334], 2.ix.1996, PM. 66°19'9"N, 151°47'41"W, 1♂ from *My. rutilus* [AF18449; UAM38333], 3.ix.1996, PM. 66°19'9"N, 151°47'41"W, 1♀ from *My. rutilus* [AF18459; UAM38343], 3.ix.1996, PM.

Remarks: This common Holarctic flea is a parasite of the voles *Myodes rutilus*, *Microtus oeconomus* and *Microtus pennsylvanicus* in Alaska. Its vestigial eye indicates it has the behaviour of a nest flea. It ranges across Alaska eastward to the Yukon Territory, then east-southeast as far as Manitoba (Holland 1985: Map 16). Its range in Alaska has several large regions that lack records: Southeast Panhandle, North Slope, extreme Southwest, Kenai Peninsula, and land in and around Prince William Sound. There appears to be a maritime factor that precludes *C. dacenkoi* from coastal habitat with a few exceptions: Unalakleet, Stebbins, St. Michael along the

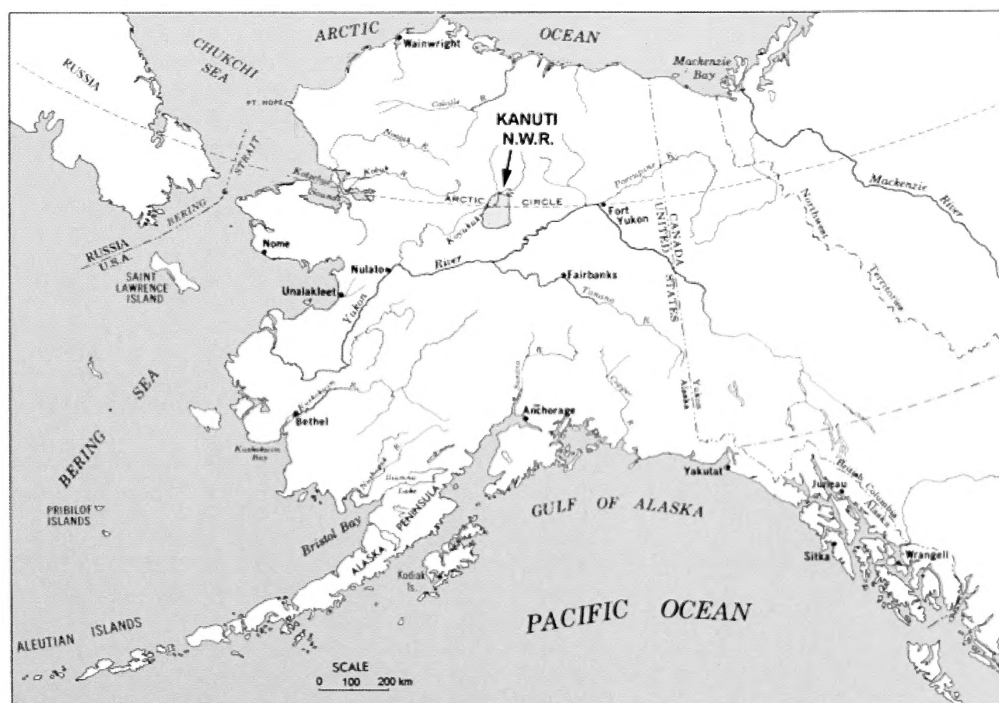


Figure 1. Map of Alaska showing central location of Kanuti National Wildlife Refuge in the upper Koyukuk River watershed and straddling the Arctic Circle.

Table 1

Seven mammalian hosts of six taxa of fleas with present records for Kanuti National Wildlife Refuge, central Alaska.

Mammal	Fleas (Siphonaptera)
Rodentia: Cricetidae <i>Lemmus trimucronatus</i> (Richardson), brown lemming	Ctenophthalmidae, Ceratophyllidae <i>Peromyscopsylla ostsibirica</i> (Scalon, 1936)
<i>Microtus oeconomus</i> (Pallas), root vole	<i>Catallagia dacenkoi</i> Ioff, 1940 <i>P. ostsibirica</i>
<i>Microtus pennsylvanicus</i> (Ord), meadow vole	<i>C. dacenkoi</i>
<i>Microtus xanthognathus</i> (Leach), taiga vole	<i>Ctenophthalmus pseudagyrtes</i> Baker, 1895 <i>Amalaraeus dissimilis</i> (Jordan, 1929)
<i>Myodes rutilus</i> (Pallas), northern red- backed vole	<i>C. dacenkoi</i> <i>P. ostsibirica</i> <i>Megabothris calcarifer</i> (Wagner, 1913) <i>A. dissimilis</i>
<i>Synaptomys borealis</i> (Richardson), northern bog lemming	<i>M. calcarifer</i>
Soricomorpha: Soricidae <i>Sorex cinereus</i> Kerr, cinereus shrew	<i>Corrodopsylla c. curvata</i> (Rothschild, 1915)

In Table 1, the mammal column shows *Microtus* spp. and *Myodes* sp. are dominant. Their fleas are almost entirely common species. The exceptional collection of the *Ctenophthalmus pseudagyrtes* specimen from *Microtus xanthognathus* in Kanuti NWR extended this flea’s continental range northward roughly 100 km. A series of three brown lemmings totaled four female *P. ostsibirica* specimens. A northern bog lemming only had one female *M. calcarifer*. Another mammal with only one female flea specimen (*C. c. curvata*) is the cinereus shrew, a rarity in Kanuti NWR that suggests testing different traps and live baits for shrews.

Bering Sea coast and at the head of Cook Inlet in Southcentral Alaska (Holland 1985: Map 16; Haas *et al.* 1989: p. 399, Map 3; MacDonald and Cook 2009: Figs. 14, 16).

Catallagia dacenkoi might have been preceded to east Beringia by its uncommon Holarctic congener *C. ioffi* Scalon, 1950, now restricted to YT, northern BC and southern Alberta. In a review of the 15 species of *Catallagia* in North America, Lewis and Haas (2001: pp. 57-59, Figs. 15, 29, 43, 57) determined that *C. jellisoni* Holland, 1954 is a junior synonym of *C. ioffi* Scalon. Its closest known approach to Alaska from the east is Swede Dome, YT (Holland 1985: p. 101, Map 17).

Corrodopsylla c. curvata (Rothschild, 1915)

Material examined: USA: AK: 66°18'43"N, 151°46'32"W, 1♀ from *Sorex cinereus* [AF17817; UAM38366], 8.viii.1996, PM.

Remarks: Only this one shrew and its single flea were collected. It took until the last year (1996) of collecting in KNWR for this success by P. Martin. *Sorex cinereus* is recorded along the Koyukuk R. and over most of Alaska but not the North Slope and the Yukon-Kuskokwim R. delta (MacDonald and Cook 2009: Map 35). Records of *C. c. curvata* are sparse in Holland (1985: p. 189, Map 36) with a large void west of the Yukon-Tanana confluence. Later however, Haas *et al.* (1989:

Map 2) recorded 19 ♂♂ and 19 ♀♀ collected by T.O. Osborne along the Yukon R. between Galena and the Yukon-Koyukuk R. confluence. Six new records of shrew fleas in western Alaska had been published (1982), and four were along the Bering Sea coast. The symbols for these records appear on distribution map 2 of Haas *et al.* (1989: p. 398). Records (Bering Sea shore): Nelson Island, Toksook Bay, 1 ♀ from *Sorex monticolus*, 25.ix.1978 and Hooper Bay, 1 ♂ from *S. monticolus*, 28.vii.1980 (Haas 1982). Scammon Bay, 2 ♂♂ 1 ♀ from *S. monticolus*, 13.vi.1980, GEH & Goodman: same data but 1 ♂ from *M. oeconomus* (Haas *et al.* 1982). Records (inland): Yukon R., Holy Cross, 1 ♀ from *S. monticolus*, 28.viii.1979 and Kuskokwim R., Tuluksak, 1 ♀ from *S. cinereus*, 1.viii.1980 (Haas *et al.* 1982).

Ctenophthalmus pseudagyrtis Baker 1895

Material examined: USA: AK: Mouse Lake, 66°18'47.22"N, 151°45'54.18"W, 1 ♀ from *Microtus xanthognathus* [AF40419; UAM87607], 25.viii.2006, LS.

Remarks: Haas *et al.* (2010) noted the incongruity of the known range of this flea with the huge range of its main host, *Microtus* spp. This collection establishes the most northerly known record of this species in Alaska and in the Koyukuk River watershed.

CERATOPHYLLIDAE

Megabothris calcarifer (Wagner, 1913)

Material examined: USA: AK: no coordinates, 1 ♂, 1 ♀ from *Myodes rutilus* [AF1585; UAM47004], 13.ix.1992, RB. 2nd record same data but [AF1577, UAM36776]. 66°19'9"N, 151°47'41"W, 1 ♀ from *My. rutilus* [AF18459; UAM38343], 3.ix.1996, PM. Mouse Lake, 66°18'47.22"N, 151°45'54.18"W, 1 ♀ from *Synaptomys borealis* [AF40305; UAM87674], 27.viii.2006, LS.

Remarks: This flea stands out as the only one of 12 that was collected in KNWR and the three villages of Allakaket, Bettles and Wiseman. This is no doubt a sign of small samples: more data are needed from KNWR. Collection data were recorded there in April, August and September. May, June and July would undoubtedly be productive. *Megabothris calcarifer* is a common and abundant Holarctic vole flea that prefers Holarctic *My. rutilus* and *Mi. oeconomus*. It ranges over much of Alaska, even as far as

Hudson Bay according to Holland (1985: Map 78). The Southeast Panhandle has no records. Four diverse distribution maps are available: Hopla (1965: Map 8); Haddow *et al.* (1983: p. 109, Map 82, as *Megabothris asio gregsoni* Holland, 1950); Holland (1985: pp. 355-359, Map 78); Haas *et al.* (1989: p. 399, Map 4). Lewis (2009) discussed the uncertain taxonomic status of the *Megabothris asio-calcarifer* complex. Are there two species in North America or only one? If two, do they each have two of more subspecies? Holland (1985: pp. 355-359) retained *M. calcarifer* for his many New Alaska Records and stated *M. asio asio* (Baker, 1904) "... has not been reported for Alaska ... " nor did he mention, list or map (77) *M. asio megacolpus* (Jordan, 1929) in Alaska.

Amalaraeus dissimilis (Jordan, 1929)

Material examined: USA: AK: 66°19.36'N, 151°46.98'W, 1 ♀ from *Microtus xanthognathus* [AF1583, UAM46995], 28.viii.1993, AZ. 66°19.4'N, 151°47.0'W, 1 ♂ from *Myodes rutilus* [AF1584; UAM47239], 28.viii.1993, AZ. 66°19'9"N, 151°47'41"W, 1 ♀ from each of 3 *My. rutilus* [AF18451 (UAM38335), AF18450 (UAM38334), AF18454 (UAM38338)] and 1 ♂ 3 ♀♀ from *My. rutilus* [AF18460 (UAM38344)], 1.ix.1996, PM. Mouse Lake, 66°19'20.94"N, 151°46'58.02"W, 7 ♀ from *My. rutilus* [AF40221 (UAM87427)], 26.viii.2006, LS.

Remarks: The most prolific, wide-ranging vole flea in Alaska except for the Southeast Panhandle is Amphi-Beringian *Amalaraeus dissimilis*. Its two preferred hosts are *Myodes rutilus* and *Microtus oeconomus*. Collections along the Koyukuk R. were successful at all study areas except Bettles. Available distribution maps are those of Hopla (1965: Map 7); Haddow *et al.* (1983: p. 14, Map 8); Holland (1985: Map 86); Lewis (2008: Fig 2A). Hopla (1965: pp. 159, 161 Table XV) noted the sustained population of this most common microtine flea throughout the year. Haas *et al.* (1989: pp. 400-401) also noted *A. dissimilis* is the most common, wide-ranging flea of *My. rutilus* and *Mi. oeconomus*. Haas (1982) found that *A. dissimilis* was more abundant in vole nests than any other species of flea found in the nests. For example: of 14 species of vole fleas found in nests in Alaska, *A. dissimilis* led in five of six measurements: Total specimens (939), Total specimens reared

(417), Maximum number in a nest (388), Number of nests infested (91) and Total number of localities (40).

LEPTOPSYLLINAE

Peromyscosylla ostsibirica (Scalon, 1936)

Material examined: USA: AK: 66°19'9"N, 151°47'41"W, 1 ♀ from *Lemmus trimucronatus* [AF17981; UAM47025], 2.ix.1996, PM & JB. 66°19'9"N, 151°47'41"W, 1 ♀ from *L. trimucronatus* [AF18400; UAM38294], 2.ix.1996, PM. 66°19'9"N, 151°47'41"W, 2 ♀♀ from *L. trimucronatus* [AF18406; UAM38300], 2.ix.1996, PM. 66°18'43"N, 151°46'32"W, 2 ♂♂ from *Microtus oeconomus* [AF17818; UAM38379], 8.viii.1996, PM. 66°19'9"N, 151°47'41"W, 1 ♂ from *Myodes rutilus* [AF18449; UAM38333], 3.ix.1996, PM. 66°18'43"N, 151°46'32"W, 1 ♂ from *Microtus pennsylvanicus* [AF17826; UAM41541], 7.viii.1996, PM. Mouse Lake, 66°19'20.94"N, 151°46'58.02"W, 1 ♂ from *My. rutilus* [AF40221; UAM87427], 26.viii.2006, LS.

DISCUSSION

Excluding missing fleas of 1991 and one of 1993, field workers were only able to collect five common species of Alaska mammal fleas from host rodents and a shrew in KNWR in 1992, 1993 and 1996 (Table 1). Two additional species of mammal fleas recorded by an earlier collector from Allakaket and Bettles are so close to KNWR that field workers can walk across the boundary to add red squirrel fleas, *Ceratophyllus vison* Baker and *Orchopeas caedens* (Jordan). The nest flea of voles, *Amphipsylla marikovskii* Ioff & Tiflov, is another species within walking distance of KNWR. The Arctic ground squirrel flea, *Oropsylla alaskensis* (Baker), occurs north and south of KNWR with no records between. Similarly, the lemming and vole flea, *Megabothris groenlandicus* Wahlgren, was recorded from *Microtus* voles at the northern location of Wiseman although there are more southern records such as along the Yukon River east of the confluence with the Koyukuk River. Brown bears, *Ursus arctos* Linnaeus, occur along the Koyukuk River and

Remarks: This flea is an Amphi-Beringian parasite of Holarctic *Microtus oeconomus*, secondarily *Myodes rutilus* with several records in the YT has most of its records in central and south-central Alaska. None is in the southeast Panhandle or the North Slope. It is primarily found in the interior forests, as in Siberia, with a few exceptions. It reaches tidewater at the head of Cook Inlet and on tundra at Nome and Unalakleet (Holland 1985: pp. 238-242, Map 51). Haas *et al.* (1989: p. 401, Map 7) noted its wide distribution in taiga and over tundra with a tidewater record at Toksook Bay, Nelson I. (Haas *et al.* 1979). A survey of fleas in vole nests confirmed collection of *P. ostsibirica* from *Mi. oeconomus* on tundra at Toksook Bay and added Goodnews Bay (Haas 1982). Hopla observed over several years that adults of *P. ostsibirica* first appeared on hosts around the end of July. Haas *et al.* (1978) agreed on the timing of adult emergence behaviour.

necessitate different flea collecting techniques by field workers who trap small mammals. The nearest bear record was on the Middle Fork near Wiseman. One female flea, *Chaetopsylla tuberculiceps* (Bezzi), was collected by an unknown technique from a Brown bear.

Holland (1985: pp. 481-487, 489-493) listed mammals that have records of fleas in Alaska. MacDonald and Cook (2009) have 13 mammal distribution maps with symbols showing where the species occur in the upper Koyukuk River watershed. Their fleas are totally unknown. Some hosts might have just one or two accidental fleas, but such records are nonetheless of interest. These potential host mammals are the following: singing vole, snowshoe hare, pygmy shrew, dusky shrew, tundra shrew, Canadian lynx, red fox, American black bear, wolverine, American marten, ermine, least weasel, American mink. Collecting fleas from carnivores can require years in the field instead of months compared with small, abundant, easily trapped and handled rodents.

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Survey of parasitoids and hyperparasitoids (Hymenoptera) of the green peach aphid, *Myzus persicae* and the foxglove aphid, *Aulacorthum solani* (Hemiptera: Aphididae) in British Columbia

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ABSTRACT

We surveyed the parasitoids and hyperparasitoids of the green peach aphid, *Myzus persicae*, and the foxglove aphid, *Aulacorthum solani* in the lower Fraser Valley of British Columbia, Canada. Field surveys were conducted using isolated pepper plants, with aphids, as trap plants. Primary parasitoids recorded from field surveys were *Aphidius ervi*, *A. matricariae*, *Praon gallicum*, *P. unicum*, *P. humulaphidis*, *Ephedrus californicus*, *Diaeretiella rapae*, *Monoctonus paulensis*, *Aphelinus abdominalis* and *A. asychis*. *Diaeretiella rapae* only emerged from green peach aphids, and *Ephedrus californicus* only emerged from foxglove aphids. *Aphidius matricariae* was the most abundant primary parasitoid species reared from both aphid species. Hyperparasitoid species collected belonged to the genera *Dendrocerus*, *Asaphes*, *Alloxysta*, *Pachyneuron* and *Syrphophagous*. In greenhouses, *Dendrocerus carpenteri* was the dominant hyperparasitoid species. *Aphidius* and *Aphelinus* spp. were attacked by hyperparasitoids at similar rates. In the field, *Aphidius* spp. were attacked by five species of hyperparasitoid, and *Aphelinus* spp. were attacked by one, *Alloxysta ramulifera*. In general, the rate of attack by hyperparasitoids was much lower in field surveys than in our collections from greenhouses.

Key Words: *Aphidius*, *Aphelinus*, *Praon*, *Dendrocerus*, *Alloxysta*, *Asaphes*, greenhouse, biological control

INTRODUCTION

The green peach aphid, *Myzus persicae* (Sulzer) and the foxglove aphid, *Aulacorthum solani* (Kaltenbach) (Hemiptera: Aphididae) are serious pests of greenhouse pepper crops (Blümel 2004, Rabasse and van Steenis 1999). In greenhouses in British Columbia (BC), Canada, these aphids may be managed in part by introduction of four different parasitoid species: *Aphidius colemani* Viereck, *A. ervi* Haliday, *A. matricariae* Haliday, (Hymenoptera: Braconidae) and *Aphelinus abdominalis* (Dalman) (Hymenoptera: Aphelinidae). In BC and elsewhere, biological control of these pests periodically fails. A number of potential, and not mutually exclusive mechanisms may be responsible: e.g., differential susceptibility to parasitoids among aphid clones (Gillespie *et al.* 2009); mismatches between parasitoid virulence and aphid susceptibility (Henry *et al.* 2005); and mortality of primary parasitoids from hyperparasitoids (Brodeur and McNeil 1994).

We postulated that additional parasitoid species would be present in the environment outside of greenhouses, and that some of these might be useful additions to the biological control arsenal for these pest aphids. Survey approaches have identified locally-present natural enemies for the BC greenhouse industry in the past (Gillespie *et al.* 1997; McGregor *et al.* 1999). Moreover, considerable, potentially useful variation in key life history attributes have been shown to be present in populations of aphid parasitoids outside of greenhouses (Henry *et al.* 2010). Thus, it is reasonable to predict that additional parasitoid species would be present in the field and that at least some of these could be exploited as commercially-produced natural enemies. Moreover, field-derived variation in life-history attributes might be exploited to address the possible biotype mismatches cited above as causes of failures in aphid biological control.

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Growers and biological control advisors have long felt that hyperparasitoid attack on primary parasitoids of aphids is involved in the periodic collapse of biological control programs in greenhouses. Schooler *et al.* (2011) have recently shown, in greenhouse cage experiments, that a hyperparasitoid, *Asaphes suspensus* (Nees) (Hymenoptera: Pteromalidae: Asaphinae) is able to eliminate populations of an aphid parasitoid, *A. ervi*, attacking pea aphids *Acyrthosiphum pisum* (Harris) (Hemiptera: Aphididae). However, little is known of the abundance or diversity of hyperparasitoids attacking the key primary parasitoids of aphid pests of greenhouse crops, either inside or outside of greenhouses. In order to study hyperparasitism-mediated

collapse of biological control, it is essential to know the identity of the species involved. Moreover, surveys might reveal species of primary parasitoids that are less susceptible to hyperparasitoid attack than the currently-available species.

We report here, the results of a survey of primary parasitoids and hyperparasitoids attacking *M. persicae* and *A. solani* on pepper, *Capsicum annuum* (L.) (Solanaceae). Our objectives were to inventory the diversity and relative abundance of parasitoids and hyperparasitoids of both *M. persicae* and *A. solani* in the lower Fraser Valley, British Columbia. We used pepper plants as trap plants in field exposures, to ensure relevance to the greenhouse system.

MATERIALS AND METHODS

Primary parasitoid survey

Surveys for primary parasitoids of *M. persicae* and *A. solani* were conducted at four locations in the lower Fraser Valley of British Columbia: Agassiz (N 49° 14.971' W 121° 45.498'), Abbotsford (N 49° 00.481' W 122° 20.024'), Langley (N 49° 06.583' W 122° 38.455'), and Ladner (N 49° 06.111' W 123° 10.251') from April to August 2005 and to a lesser extent in 2006.

As a survey tool, we used pepper plants, *Capsicum annuum* L., "Bell Boy" (Stokes Seeds, St. Catharines, Ontario, Canada), which hosted large populations of one of the two target aphid species. These were placed into survey sites for 3 days. Pepper plants were seeded in a soilless mixture (70% peat, 30% Perlite), transplanted to 1 L pots in soilless mixture after 2 weeks, and grown in a greenhouse under 16 h daylength. After 8 to 10 weeks, these were transplanted to a soilless medium (peat and perlite) in 4 L pots and used in surveys. We inoculated these plants with aphids from laboratory colonies. Excised pepper leaves containing approximately 200 mixed stages of either *M. persicae* or *A. solani* aphids were placed on pepper plants. The two target aphid species were each placed on different plants. Aphid populations increased in isolation cages on greenhouse benches for 7 to 14 days, prior to field exposure. At time of field exposure, each plant contained approximately 2000 aphids, and these were predominantly immature stages. Some alate

adults were present, but we did not determine the relative frequency of these.

Each pepper plant, with aphids was placed on a pedestal in a tray of water, and surrounded by a cylindrical cage, 43 cm dia x 56 cm tall, constructed of 1 cm square wire mesh. This cage prevented larger, generalist predators from accessing the aphids, and the tray of water mostly prevented slugs (Mollusca) from consuming the plant. Pepper plants at each location were placed in three separate sites within 500 m of each other within each location. Thus, there were six total plants (three with *M. persicae* and three with *A. solani*) at each of four locations on each survey date. After 3 days of exposure, the plants were collected, and held in 1m³cages covered with very fine mesh, on greenhouse benches. The plants were inspected daily and any mummies that formed were removed from the plant with a fine brush or on small leaf pieces that were cut from the plant with a scalpel. The mummies were placed individually in #00 gelatine capsules (T. U. B. Enterprises, Almonte, Ontario, Canada) for emergence of the adult parasitoid or hyperparasitoid. These were then either pointed on insect pins, or preserved in 70% ethanol, for taxonomic identification. A subset of material on insect pins was shipped to taxonomic specialists (primarily Dr. K. Pike, and Dr. M. Mackauer) for comparison with specimens in their collections. We used voucher material from these specialists, and

from the Canadian National Collection of Arthropods, Ottawa, combined with generic descriptions and taxonomic keys in van Achterberg (1997), and species descriptions and taxonomic keys in Ferrière (1965), Mackauer (1968), Graham (1976), Pike *et al.* (1977), Powell (1982), Johnson (1987), Mescheloff and Rosen (1990), Hayat (1998), Takada (2002) and Kavallieratos *et al.* (2005).

We investigated the effects of host species and location on diversity of parasitoids using a simple Berger-Parker dominance index (Southwood 1978). For each sample we calculated the abundance of the dominant species across all samples (*A. matricariae*) relative to the total number of individuals in the sample. An ANOVA model was used that included both of the above factors and their interaction, and because the dominance index is essentially a proportion, we transformed these data [$\arcsin(x^{0.5})$] for analysis, although we report the raw proportions. At each location, plants were located in three places separated by at least 500 m. Although these could be considered a form of pseudoreplication, we judged that the separation was sufficient to render these as independent samples, and we used this replication in the model. We also used date of placement as replication. Again, although this is not strictly correct, survey plants were not placed continuously at each location and we therefore considered each survey date as an independent sample of parasitoid diversity at the location.

Due to scheduling and handling time issues, plants were placed into sites at different times. Therefore, we could not use time of placement as an analysis variable. We grouped the results by month of exposure to hosts and host species, which allowed a visual analysis of the trends in parasitoid community composition for each host aphid.

Hyperparasitoid survey

We conducted both greenhouse and field surveys for hyperparasitoids. Surveys for hyperparasitoids of *M. persicae* and *A. solani* on peppers in greenhouses in British Columbia were done in four greenhouse operations, from June – October, 2006. These greenhouses had not been sprayed within 4

weeks of the survey date and had aphids and primary parasitoid mummies present. Mummies were collected from pepper plants and placed individually in #00 gelatine capsules as above. These were held until adult primary parasitoids or hyperparasitoids emerged. Adult hyperparasitoids were preserved in 70% ethanol and later identified to species. We stopped surveys when greenhouse operators treated with insecticides, mainly because live material was subsequently impossible to find.

Field surveys for hyperparasitoids of *M. persicae* and *A. solani* were conducted at four locations in the lower Fraser valley of British Columbia: Agassiz (N 49 14.971' W 121 45.498'), Abbotsford (N 49 00.481' W 122 20.024'), Langley (N 49 06.583' W 122 38.455'), and Ladner (N 49 06.111' W 123 10.251'), monthly from May to August 2005 and at least four plants with each aphid host were placed at each location on each date. Aphids were exposed at survey sites for three days, using the same methods as for the primary parasitoid survey. These plants were returned to the greenhouse at the research centre and held in cages until mummies began to form. When mummies began to form, the plants were then returned to the field locations for 3 days. At this time the survey plants contained both fully formed mummies and parasitoid larvae inside hosts. This provided opportunities for both endophagous (female wasp deposits eggs inside the primary parasitoid larva while it is still developing inside the live aphid, before aphid is mummified) and ectophagous (female wasp deposits her egg on the surface of the primary parasitoid larva or pupa after the aphid is killed and mummified) hyperparasitoid species to find hosts. When the plants were returned to the greenhouse the mummies, and any that formed afterward, were removed from plants as above and held for emergence of primary or hyperparasitoid species. We used taxonomic keys and species descriptions in Graham (1969), Andrews (1976), Fergusson (1980), Powell (1982), Pike *et al.* (1997), and Gibson and Vikberg (1998) to identify the specimens to the species level.

RESULTS AND DISCUSSION

Primary parasitoids

Nine primary parasitoid species were identified from each of the aphid species (Table 1). In addition, a small number of unidentifiable *Aphidius* and *Aphelinus* specimens were reared. The diversity and relative abundance of primary parasitoid species was almost identical between the two pest species (Table 1). *Diaretiella rapae* (M'Intosh) (Hymenoptera: Braconidae) was only reared from *M. persicae*, and *Ephedrus californicus* Baker (Hymenoptera: Braconidae) was only reared from *A. solani*. In general, fewer primary parasitoids were collected from pepper plants baited with *A. solani*, than from those baited with *M. persicae*. This is likely because *A. solani* drops from plants in response to parasitoid attack (Gillespie and Acheampong 2012), resulting in fewer parasitoid offspring on the plants. In comparison, we have observed that *M. persicae* rarely drops from plants in response to parasitoid attack.

Mackauer and Starý (1967) recorded 34 described species attacking *M. persicae* and 15 attacking *A. solani*. Records for *Aphelinus* spp. in Dunn (1949), Schlinger and Hall (1960), Shands *et al.* (1965), Mackauer (1968) and Kavallieratos *et al.* (2010) add an

additional four species for *M. persicae* and one for *A. solani*. Based on published surveys, the number of parasitoids actually reared from *M. persicae* in any given region ranges from five to ten, and for *A. solani*, from one to five. The dominant complex on both hosts generally consists of one or two *Aphidius* spp, a *Praon* species and an *Aphelinus* species. Our survey recorded no new parasitoid associations for *M. persicae*. The primary parasitoid community that we found attacking *M. persicae* is very similar to that found elsewhere. The primary parasitoid community attacking *A. solani* is considerably more diverse than found elsewhere. This may be due to our survey methods, which entailed placing hosts into the field on isolated plants, as opposed to the plant inspection and general collection methods used by others. It appears that *Praon gallicum* Starý, *P. humulaphidis* Ashmead, *Monoctonus paulensis* (Ashmead) and *Ephedrus californicus* Baker (Hymenoptera: Braconidae) have not been reared previously from *A. solani*, and thus these constitute new host records.

The generalist parasitoid, *Aphidius matricariae* Haliday (Hymenoptera: Braconidae), was the most abundant species on both aphid species (Table 1). It has been

Table 1
Percent of species in the parasitoid complex of *Myzus persicae* and *Aulacorthum solani*, reared from pepper plants with the indicated aphid species exposed in the field at four different locations in 2005 and 2006.

Primary parasitoid	Aphid host	
	<i>Myzus persicae</i>	<i>Aulacorthum solani</i>
<i>Aphidius ervi</i>	6.7	3.9
<i>Aphidius matricariae</i>	48	54.7
<i>Aphidius</i> spp.	0.7	1.7
<i>Praon gallicum</i>	3.5	10.1
<i>Praon unicum</i>	15.5	4.1
<i>Praon humulaphidis</i>	0.2	1
<i>Diaretiella rapae</i>	1.2	0
<i>Aphelinus asychis</i>	3.6	0.2
<i>Aphelinus abdominalis</i>	16.7	21.1
<i>Aphelinus</i> spp.	1.2	0.5
<i>Monoctonus paulensis</i>	0.5	0.3
<i>Ephedrus californicus</i>	0	0.3
Hyperparasitoids	1.7	0.3
Total number reared	2585	583

recorded as the dominant parasitoid of *M. persicae* by many authors (e.g., Dunn 1949, Schlinger and Hall 1960, Mackauer 1968, Shands *et al.* 1972, Devi *et al.* 1999). It is known to be effective for the control of the green peach aphid on sweet pepper (Rabasse and Shalaby 1980). This species was apparently accidentally introduced into North America (Schlinger and Mackauer 1963, Mackauer 1968). However, it was reported to be reared at the Belleville biological control laboratory [under a synonym, and as a native, *Aphidius phorodontis* Ashmead (Hymenoptera: Braconidae)], and widely shipped to Canadian greenhouse growers for biological control of *M. persicae* in 1938, 1939 and 1940 (McLeod 1962). It is presently commercially reared for release as a biological control agent, particularly for control of green peach aphids. *Aphidius matricariae* has not previously been reported to be abundant on *A. solani* although it has been reared from this host (Mackauer and Starý 1967, Dunn 1949, Kavallieratos *et al.* 2010). Laboratory experiments indicate that under choice conditions, *A. matricariae* selects *M. persicae* as hosts in preference to *A. solani* (Acheampong & Gillespie unpublished data). The abundance of *A. matricariae* on *A. solani* may simply be due to an abundance of *A. matricariae* adults in the habitat, either because of the concentrations of hosts and honeydew signals on our trap plants (Bouchard and Cloutier 1985) or the abundance of alternative hosts in the habitats in which we placed our survey plants. Because we did not survey abundance of parasitoid adults in those habitats, there is no evidence to support either of these competing explanations.

Aphidius ervi Haliday, which is currently released in greenhouses for biological control of *A. solani* and *Macrosiphum euphorbiae* (Thomas) (Hemiptera: Aphididae) by some growers in BC, was less common than *A. matricariae*. This species was introduced into western North America from Europe in the 1960s for biological control of pea aphids, *Acyrtosiphon pisum* (Harris) (Hemiptera: Aphididae) (Mackauer and Starý 1967). Although there are field collection records of *A. ervi* from both *M. persicae* and *A. solani* (e.g. Kavallieratos *et al.* 2010) this parasitoid is not widely reared in the field from either

host. Takada and Tada (2000) did not rear this species from field collections of either host in Japan, and Mackauer and Starý (1967) considered records on *A. solani* and *M. persicae* to be suspect. Henry *et al.* (2005, 2006) found that *A. ervi* is not particularly adapted to using *A. solani* as hosts until it has been reared for several generations on that host.

It is important to note that we did not rear any specimens of *Aphidius colemani* Viereck (Hymenoptera: Braconidae). This species is intensively released for biological control of aphids in greenhouse crops in the region. It has been recovered from cereal fields in Germany, where it is also released for biological control of aphids in greenhouses (Adisu *et al.* 2002). It is conceivable that some specimens of this species were present among the *A. matricariae* specimens. The species are very similar in general appearance (M. Mackauer, pers. comm.), and some could have been overlooked. Pike *et al.* (1996) report a single specimen of *A. colemani* reared from an unidentified aphid in Washington State. A molecular analysis of field collections of *A. matricariae* is likely needed to resolve this question in British Columbia.

Aphelinus asychis Walker and *Aphelinus abdominalis* (Dalman) (Hymenoptera: Aphelinidae) were present on both *M. persicae* and *A. solani*. *Aphelinus abdominalis* was more abundant than *A. asychis* on both hosts. *Aphelinus abdominalis* is of European origin, and has been used extensively for biological control of aphids in greenhouses in North America since 1998 (Gillespie *et al.* 2002), but it is not clear if this application was the first release in North America. It is extensively released for biological control of aphids in greenhouses in British Columbia. *Aphelinus asychis* was released into North America in Texas, for biological control of *Schizaphis graminum* (Rondani) (Hemiptera: Aphididae) in the late 1960s (Jackson 1971) and has since been widely re-distributed. Neither species is recorded in any of the earlier general field surveys in North America (MacGillivray and Spicer 1953; Shands *et al.* 1955, 1965; Schlinger and Hall 1960). Mackauer (1968) reports *A. asychis* to be a parasitoid of *M. persicae* in Europe and *A. semiflavus* Howard to fill the same role in North America. *Aphelinus semiflavus* is

widely recorded as a parasitoid of *M. persicae* and *A. solani* but this species was not reared in our survey. In Japan, *A. solani* was not a suitable host for *A. abdominalis*, but was highly suitable for *A. asychis* (Takada 2002). Our survey results suggest an opposite trend, but the abundance of *A. abdominalis* could be an artifact resulting from a combination of releases in protected agriculture combined with an abundance of highly suitable alternative hosts in the field.

Of the remaining parasitoid species, the *Praon* spp. were common as a group. *Praon unicum* Smith was common on *M. persicae*, and *P. gallicum* on *A. solani*. *Praon humulaphidis* Ashmead was not reared during extensive surveys in 2005, but was reared from both hosts during selected exposures of aphids on pepper plants in 2006, and so is included as a host record in the survey results. Johnson (1987) reports that *P. gallicum* was introduced into North America for biological control of *S. graminum*, and that a *Praon* sp. reported by Shands *et al.* (1965) on both *A. solani* and *M. persicae* was actually *P. gallicum*. Thus this species is either native to North America, or was introduced at some time previous to 1965, and it is important to note that the species was not described, from European specimens, until 1971 (Stárý 1971). Jansen (2005) reared *P. gallicum* from both *A. solani* and *M. persicae* in a survey in Belgium, and Schlinger and Hall (1960) reared *P. unicum* from *M. persicae* in Riverside, CA. Raworth *et al.* (2008) reported *P. unicum* to be important in the regulation of aphid populations on blueberry (*Vaccinium corymbosum*). Other surveys have found different *Praon* spp. on the two aphid hosts, particularly *Praon volucre* Haliday in Europe, and *Praon occidentale* Baker in North American surveys. In general, species in this genus are consistently present in surveys, but are not particularly abundant. Species of both *Aphidius* and *Aphelinus* are exploited as commercially reared biological control agents, but at this time, no *Praon* spp. are reared for release against *M. persicae* or *A. solani* in North America.

The diversity of parasitoids, based on the Berger-Parker dominance index (Number of *A. matricariae*/total parasitoids from the location) was different between locations (0.67 ± 0.093 , 0.20 ± 0.103 , 0.58 ± 0.133 and

0.41 ± 0.115 for Abbotsford, Agassiz, Ladner and Langley, respectively; Anova, F3, 55 = 3.26, $P = 0.0279$). The Agassiz samples were the most diverse (least dominated by *A. matricariae*), compared to the Abbotsford (most dominated by *A. matricariae*), and the samples from Langley and Ladner were intermediate, and not different from each other or the extremes. The Berger-Parker dominance index was also affected by aphid species (F1, 55 = 10.40, $P = 0.0021$), with the samples from *M. persicae* being considerably more dominated by *A. matricariae* than those from *A. solani* (0.62 ± 0.075 and 0.28 ± 0.082 , for *M. persicae* and *A. solani*, respectively). The differences between the two aphid species are not surprising since *A. matricariae* is a dominant parasitoid on *M. persicae* in almost all literature reports, whereas this parasitoid is not often recorded from *A. solani*. The differences between locations may reflect a number of factors relating to both plant community and agronomic practice in the different locations. For example, plants at the Agassiz location, were located in proximity to native forest habitat with considerable plant diversity, and were not bordered on all sides by agricultural habitat. In contrast, the Abbotsford plants were in close proximity to commercial raspberry production, with comparatively low plant diversity. The differences in plant diversity may imply similar differences in aphid and parasitoid diversity in surrounding habitats, but these ideas are preliminary, and would need to be tested rigorously with better-designed surveys.

The proportion of each parasitoid species on the two aphid hosts appeared to vary through the survey period. *Aphidius matricariae* was almost absent on *M. persicae* in April, although it was the dominant parasitoid thereafter. Conversely, *A. matricariae* was relatively common on *A. solani* in April and May, and generally decreased in abundance thereafter. *Praon unicum* was only present on both species in the May samples, which is consistent with the observations of Raworth *et al.* (2008), who found that this parasitoid is an early-season species on *Vaccinium*. *Aphelinus abdominalis* was abundant on *M. persicae* in April, yet did not continue to be common, whereas on *A. solani* this parasitoid was common throughout the survey. There are a number of other trends

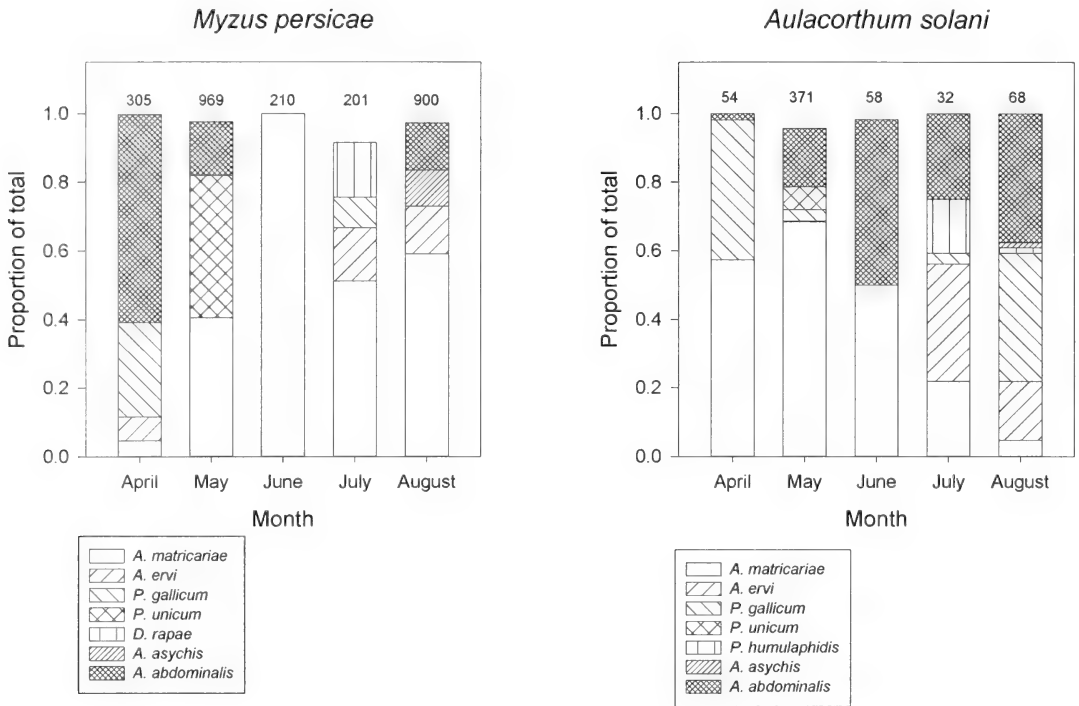


Figure 1. Proportion of parasitoids reared from *M. persicae* and *A. solani* during five months of sampling at four locations in British Columbia. The numbers over each bar represent the total number of primary parasitoids on which the proportions are based.

in species composition that could be constructed from Figure 1. However, these data are derived primarily from one year of survey so it is not clear if the trends apply to all years or are unique to the survey period. Again additional survey is required to determine if these are valid trends.

Hyperparasitoids

The primary parasitoid survey yielded a relatively low frequency of hyperparasitoids (Table 1). This was likely due to the relatively short exposure time, which removed hosts from the field before mummies had formed. In hyperparasitoid surveys, we placed plants back into the field after mummies of the primary parasitoids had begun to form, and we found considerably greater diversity and abundance of hyperparasitoids.

From primary parasitoid mummies that we placed into our field survey locations we reared six species of hyperparasitoids, and two other species we could only identify to genus (Table 2). Collectively, the *Alloxysta* spp. (Hymenoptera: Charipidae: Alloxystinae) were the majority of the hyperparasitoids. *Dendrocerus carpenteri* (Curtis)

(Hymenoptera: Megaspilidae) was next in abundance, and was the single most abundant species. Three *Asaphes* species (Hymenoptera: Pteromalidae) comprised the remainder. Although the majority of the hyperparasitoid species were reared from *Aphidius* species, *Aphelinus* species were attacked by *Alloxysta ramulifera* Thompson, and *Praon* mummies were attacked by an *Alloxysta* sp., and by *Asaphes suspensus* (Nees). The aggregate rate of hyperparasitism did not exceed 10% in any collections (Table 2). It is important to note that this intensity of attack resulted from exposure of mummies and maturing larvae of the primary parasitoids for only three days, and that these plants had also been previously exposed in the field to collect a community of the primary parasitoids. Longer exposures would likely have resulted in higher rates of hyperparasitism. We do not record the primary parasitoid host to species because we could not be absolutely sure of the identity of the mummies. However, based on the primary parasitoid survey, the majority of hosts were *A. matricariae*, and *Aphelinus abdominalis*. All of the associations between primary

Table 2
Numbers of hyperparasitoid species emerging from primary parasitoid mummies exposed in the field at four different locations in British Columbia, 2005

Location	Month	# of plants	# of plants with primary parasitoids	# of plants with hyperparasitoids	# of primary parasitoids	# of hyperparasitoids	Hyperparasitoid species	Host mummy
Abbotsford	April/May	12	9	0	198	0		
	June	16	13	1	637	4	<i>Alloxysta</i> sp.	<i>Aphidius</i>
	July	12	11	1	340	10	<i>Dendrocerus carpenteri</i>	<i>Aphidius</i>
							<i>Dendrocerus carpenteri</i>	<i>Aphidius</i>
	August	23	15	5	429	19	<i>Dendrocerus carpenteri</i>	<i>Aphidius</i>
						3	<i>Alloxysta</i> sp.	<i>Aphidius</i>
						6	<i>Asaphes suspensus</i>	<i>Aphidius</i>
						9	<i>Asaphes</i> sp.	<i>Aphidius</i>
	September	8	3	0	70	0		
Agassiz	April/May	12	4	0	39	0		
	June	16	12	2	737	1	<i>Alloxysta</i> sp.	<i>Praon</i>
						2	<i>Alloxysta</i> sp.	<i>Aphidius</i>
	July	12	7	1	359	2	<i>Alloxysta victrix</i>	<i>Aphidius</i>
	August	20	10	0	742	0		
	September	12	6	1	99	4	<i>Asaphes suspensus</i>	<i>Praon</i>
Ladner	April/May	12	7	0	344	0		
	June	16	11	3	740	26	<i>Asaphes californicus</i>	<i>Aphidius</i>
							<i>Alloxysta victrix</i>	<i>Aphidius</i>
	July	12	11	5	495	3	<i>Alloxysta brassicae</i>	<i>Aphidius</i>
						47		
Langley	August	20	10	0	530	0		
	April/May	12	5	1	288	17	<i>Dendrocerus carpenteri</i>	<i>Aphidius</i>
							<i>Dendrocerus carpenteri</i>	<i>Aphidius</i>
	June	16	12	1	140	1	<i>Alloxysta brassicae</i>	<i>Aphidius</i>
						16	<i>Alloxysta sp.</i>	<i>Aphelinus</i>
						10	<i>Alloxysta victrix</i>	<i>Aphidius</i>
	July	12	11	4	437	30	<i>Alloxysta ramulifera</i>	<i>Aphelinus</i>
						73	<i>Alloxysta ramulifera</i>	<i>Aphelinus</i>

parasitoid genera and hyperparasitoids have been previously recorded.

We identified six hyperparasitoid species attacking primary parasitoid mummies collected from greenhouses, and reared a further three species that we could identify only to genus (Table 3). In all the greenhouses surveyed, *D. carpenteri* was the most abundant hyperparasitoid species (Table 3). The hyperparasitoid complexes were quite different between the two most common primary parasitoid mummy types. The majority of hyperparasitoids that emerged from *Aphidius* mummies in all greenhouses were *D. carpenteri*. This species was also

present on *Aphelinus* mummies, but was not the dominant hyperparasitoid on that host in any greenhouse. Three *Asaphes* species collectively dominated the community of hyperparasitoids attacking *Aphelinus* mummies. Only one *Praon* mummy was collected from the greenhouse survey and an *A. suspensus* hyperparasitoid emerged from it. The community of hyperparasitoids appears to be quite different between field and greenhouse collections. In the field, the *Alloxysta* species dominated and *Asaphes* spp. were not common. In contrast, the *Asaphes* species were common in greenhouses while the *Alloxysta* spp. were not. *Asaphes* spp. have

Table 3

Numbers of hyperparasitoids emerging from primary parasitoid mummies collected from pepper plants in greenhouses in British Columbia, 2006

Greenhouse	Primary parasitoid genus	# of primary parasitoids	# of hyper-parasitoids	<i>D. carpenteri</i>	<i>A. californicus</i>	<i>A. suspensus</i>	<i>Asaphes</i> sp	<i>Pachyneuron aphidis</i>	<i>A. brassicae</i>	<i>A. victrix</i>	<i>Alloxysta</i> sp.	<i>Syrphophagus</i> sp.
A	Aphidius	324	28	25	3	0	0	0	0	0	0	0
A	Aphelinus	0	0	0	0	0	0	0	0	0	0	0
B	Aphidius	114	75	40	0	0	0	35	0	0	0	0
B	Aphelinus	12	6	0	0	3	0	3	0	0	0	0
C	Aphidius	1340	129	84	9	19	0	10	1	4	0	2
C	Aphelinus	64	3	1	0	0	0	0	0	0	2	0
C	Praon	1	1	0	0	1	0	0	0	0	0	0
D	Aphidius	254	217	152	20	32	7	3	1	0	2	0
D	Aphelinus	85	43	20	9	9	5	0	0	0	0	0
Total ¹			502	322	41	64	12	51	2	4	4	2
Percent ²				64.1	8.2	12.7	2.4	10.2	0.4	0.8	0.8	0.4

- 1. Total primary parasitoid mummies collected from greenhouses
- 2. Percent of each species in the total hyperparasitoid community

a higher temperature threshold than their parasitoid hosts (Campbell *et al.* 1974) and might therefore be more successful in greenhouse than in field settings. *Dendrocerus carpenteri* was common in both habitats. Although differences in the greenhouse and field environments might account for the differences in hyperparasitoid communities, it is equally possible that community assembly has a strong random component, and that the community that we found in our surveys is determined to a large extent in both habitats by which species are the first invaders.

The greenhouses each had quite different histories, and thus we did not pool data for these surveys (Table 3). Greenhouse A, where the hyperparasitism rate was low, was treated with insecticides for a pest other than aphids, and sampling was discontinued. In greenhouse B, the hyperparasitism rate – i.e., the percent of primary parasitoid mummies that yielded a hyperparasitoid – was high (60.32%) in July, and the greenhouse was treated for aphids with an insecticide. Hyperparasitism peaked in greenhouse C in August (61.54%) and in greenhouse D at the end of August and early September, at 77.78 and 77.38% respectively. Greenhouse D was sprayed for aphids in September and the survey was terminated. Greenhouse C, a propagation house at the Agriculture and Agri-Food Research Centre, Agassiz, was not sprayed during the survey

period. For greenhouse C, there was an increase in hyperparasitism from June to July and a peak level of hyperparasitism, with a subsequent decrease in hyperparasitism rate in September and October. Across all greenhouses, the level of hyperparasitism of primary parasitoid species was similar for *Aphidius* and *Aphelinus* species, at 32.28 and 34.78%, respectively. This demonstrates that the two genera are equally vulnerable to attack by hyperparasitoids in greenhouses. *Alloxysta ramulifera* was the dominant hyperparasitoid species reared from *Aphelinus* species in the field. This species was not collected from the greenhouse survey. The recovery of hyperparasitoid species from *Aphelinus* is particularly significant, as this species is thought to not be attacked by hyperparasitoids in greenhouse systems. There may be undiscovered impacts of hyperparasitoids on *Aphelinus* in greenhouses in BC which could worsen if *A. ramulifera* migrates from the field into greenhouses.

Hyperparasitism could be a limiting factor in the biological control of aphids in greenhouses, since these are essentially large cages with limited opportunities for refuge for the primary parasitoid hosts. Mackauer and Völkl (1993) argued that hyperparasitoids would be unable to limit the actions of primary parasitoids of aphids because of low lifetime fecundity and limited egg supply in the hyperparasitoids, as long as the parasitoids

are able to escape by dispersal. Schooler *et al.* (2011) demonstrated that *Asaphes suspensus* could drive *Aphidius ervi* to extinction after four generations in large multiple-plant cages, and their result is highly relevant to greenhouse agriculture. In our greenhouse surveys, a high rate of hyperparasitism was associated with the collapse of biological control of aphids, but it was not clear that there was a causal relationship.

The objectives of our survey were to identify parasitoid species in the community in BC that could potentially be exploited as

biological control agents for *M. persicae* and *A. solani* in greenhouse crops. We identified three *Praon* species that could be further evaluated. *Aphelinus asychis* and *Aphidius matricariae* occurred on *A. solani* and might be host-adapted strains that could be integrated into biological control programs. We surveyed the biodiversity of hyperparasitoids and demonstrated that there are several species that might be of concern, but their impacts on population dynamics require further study.

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Updated checklist of the Orthoptera of British Columbia.

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ABSTRACT

Since the last publication of a checklist of the Orthoptera of British Columbia, much has been learned about the group. New information has come from a variety of web-based resources as well as new collections. An updated checklist is presented, listing 104 resident species in the province. Two of these species are represented by two subspecies in BC. Eight species have been added since the last list was published, including newly discovered native species and newly established non-native species. Records of six species have been found to be based on misidentified specimens and these species have been deleted from the checklist. An additional 15 species are considered hypothetical and may one day be confirmed to occur in BC.

Key Words: Orthoptera, British Columbia, Checklist

INTRODUCTION

The basis for understanding the Orthoptera of British Columbia (and Canada) is the Agriculture Canada handbook published in 1985 (Vickery and Kevan 1985). While the handbook was in preparation, a number of taxonomic changes were proposed by Otte (1981, 1984). These changes necessitated updates to the information presented in the handbook (Vickery 1987) and the publication of a new checklist (Vickery and Scudder 1987). Since that time, there have been a number of changes in both the taxonomy of the order and the state of knowledge of the provincial insect fauna. The advent of the Orthoptera Species File Online (Eades et. al 2012) has provided easy access to authoritative and up to date taxonomic

information. Other web-based developments, such as the Singing Insects of North America (Walker and Moore 2012), Bugguide (Iowa State University 2003 – 2012), and efauna (Klinkenberg 2012), have provided information to a wider audience and raised the public profile of Orthoptera and other insects. At the same time, submissions to these websites from the naturalist community have provided unusual records and added to our knowledge of the Orthoptera of BC. Recent field collections have also contributed greatly to our understanding of the group. Presented here is an updated checklist of the Orthoptera of BC, with an explanation of changes to the 1987 list.

MATERIALS AND METHODS

Beginning in 2005, the staff and volunteers of the Royal British Columbia Museum (RBCM) have increasingly targeted Orthoptera during field collections. A number of collecting events have specifically focused on Orthoptera in regions of the province known to have high diversity, records of under-collected species, or a lack of historic records. At the same time, the British Columbia Ministry of Environment has collected Orthoptera during insect sampling throughout the southern portion of the

province. Both the RBCM and the Ministry of Environment have been successful in soliciting donations of specimens collected by private companies and community organizations engaged in a variety of biodiversity studies. Examination of specimens from all sources has yielded several new species for the province and has provided new distributional data for more than half of the species now known from BC.

The author has critically examined the Orthoptera collections of the RBCM, the

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Lyman Entomological Museum (Montreal), the Canadian National Collection (Ottawa) and the Royal Ontario Museum (Toronto).

RESULTS AND DISCUSSION

An updated checklist to the Orthoptera of BC is presented in Table 1.

Taxonomic changes

The following species are listed here differently than in previous checklists. These taxonomic changes are according to Eades *et al.* (2012) unless another source is identified.

Arphia pseudonietana pseudonietana (Thomas 1870) is listed here as *Arphia pseudonietana* (Thomas 1870); no subspecies are recognized.

Chorthippus curtipennis curtipennis (Harris 1835) is listed here as *Pseudochorthippus curtipennis curtipennis* (Harris 1835).

Circotettix rabula rabula Rehn and Hebard 1906 is listed here as *Circotettix rabula* Rehn and Hebard 1906; no subspecies are recognized.

Circotettix undulatus undulatus (Thomas 1872) is listed here as *Circotettix undulatus* (Thomas 1872); no subspecies are recognized.

Melanoplus femurrubrum femurrubrum (De Geer 1773) is listed here as *Melanoplus femurrubrum* (De Geer 1773); no subspecies are recognized.

Melanoplus kennicottii kennicottii Scudder 1878 is listed here as *Melanoplus kennicotti* Scudder 1878; no subspecies are recognized; the spelling is corrected.

Melanoplus occidentalis occidentalis (Thomas 1872) is listed here as *Melanoplus occidentalis* (Thomas 1872); no subspecies are recognized.

Orphulella pelidna desereta Scudder 1899 is listed here as *Orphulella pelidna* (Burmeister 1838); no subspecies are recognized.

Psoloessa delicatula buckelli Rehn 1937 is listed here as *Psoloessa delicatula* (Scudder 1876); no subspecies are recognized.

Sphagniana sphagnum (F. Walker 1869) is listed here as *Metrioptera sphagnum* (F. Walker 1869). The species was included in the genus *Metrioptera* in the most recent revision of North American Tettigoniinae (Rentz and Birchim 1968).

These examinations revealed a number of identification errors and previously unrecognized species.

Trimerotropis suffusa Scudder 1876 is listed here as *T. verruculata suffusa* Scudder 1876.

Trimerotropis verruculata (Kirby 1837) is listed here as *T. verruculata verruculata* (Kirby 1837).

Xanthippus buckelli Hebard 1928 has been synonymised with *Xanthippus corallipes* (Haldeman 1852).

Additions to the checklist of the Orthoptera of BC

Conocephalus dorsalis (Latreille 1804): A non-native species established in the Fraser Delta (Miskelly, in prep.) (RBCM and UBC specimens).

Meconema thalassinum (De Geer 1773): A non-native species well-established in the Fraser Valley (Cannings *et al.* 2007) and Victoria area (RBCM specimens).

Melanoplus digitifer Hebard 1936: Collected by RBCM in the Selkirk Mountains in 2008. Subsequently, a group of specimens from the same area that had been misidentified as *Melanoplus oregonensis triangularis* Hebard 1928 was found in the Lyman collection. Since 2008, *M. digitifer* has been collected at several locations in BC in the southern Selkirk Mountains (RBCM specimens).

Oedaleonotus enigma (Scudder 1876): Collected in BC (and Canada) for the first time by the BC Ministry of Environment in Osoyoos in 2010 (RBCM specimens).

Orchelimum gladiator Bruner 1891: Though not previously recorded in BC, two specimens were found in existing collections. One specimen in the RBCM collection was collected in Creston in 1991 and identified correctly. The second, found in the UBC collection, was collected in Myncaster in 1998 and misidentified as *Conocephalus fasciatus* (De Geer 1773). Since 2008, *O. gladiator* has been collected at many locations from Christina Lake to Fernie (RBCM specimens).

Steiroxys: This genus is in need of revision and no British Columbian specimens have been identified to species. However, there

Table 1

Checklist of the Orthoptera of British Columbia. I = Introduced species. A = Addition since previous checklist.

Family	Subfamily	Species
Stenopelmatidae	Stenopelmatinae	<i>Stenopelmatus fuscus</i> Haldeman 1852 <i>Stenopelmatus longispinus</i> Brunner von Wattenwyl 1888
Rhaphidophoridae	Ceuthophilinae	<i>Ceuthophilus agassizii</i> (Scudder 1861) <i>Ceuthophilus alpinus</i> Scudder 1894 <i>Ceuthophilus vicinus</i> Hubbell 1936 <i>Pristoceuthophilus celatus</i> (Scudder 1894) <i>Pristoceuthophilus cercalis</i> Caudell 1916 <i>Pristoceuthophilus pacificus</i> (Thomas 1872) <i>Tropodischia xanthostoma</i> (Scudder 1861)
Prophalangopsidae	Tropodischiinae	
	Cyphoderrinae	<i>Cyphoderris buckelli</i> Hebard 1934 <i>Cyphoderris monstrosa</i> Uhler 1864
Tettigoniidae	Conocephalinae	<i>Conocephalus dorsalis</i> (Latreille 1804) ^{I, A} <i>Conocephalus fasciatus</i> (De Geer 1773) <i>Orchelimum gladiator</i> Bruner 1891 ^A
	Meconematinae	<i>Meconema thalassinum</i> (De Geer 1773) ^{I, A}
	Phaneropterinae	<i>Scudderia furcata furcata</i> Brunner von Wattenwyl 1878 <i>Scudderia pistillata</i> Brunner von Wattenwyl 1878
	Tettigoniinae	<i>Anabrus longipes</i> Caudell 1907 <i>Anabrus simplex</i> Haldeman 1852 <i>Apote robusta</i> Caudell 1907 <i>Metrioptera sphagnorum</i> (F. Walker 1869) <i>Neduba steindachneri</i> (Herman 1874) <i>Peranabrus scabricollis</i> (Thomas 1872) <i>Steiroxys cf. strepens</i> Fulton 1930 ^A <i>Steiroxys cf. trilineata</i> (Thomas 1870) ^A <i>Steiroxys undescribed species</i> ^A
Gryllidae	Gryllinae	<i>Acheta domesticus</i> (Linnaeus 1758) ^I <i>Gryllus pennsylvanicus</i> Burmeister 1838 <i>Gryllus veletis</i> (Alexander and Bigelow 1960)
	Oecanthinae	<i>Oecanthus argentinus</i> Saussure 1874 <i>Oecanthus californicus californicus</i> Saussure 1874 <i>Oecanthus fultoni</i> T. J. Walker 1962 <i>Oecanthus quadripunctatus</i> Beutenmuller 1894 <i>Oecanthus rileyi</i> Baker 1905
	Nemobiinae	<i>Allonemobius allardi</i> (Alexander and Thomas 1959) <i>Allonemobius fasciatus</i> (De Geer 1773)
Myrmecophilidae	Myrmecophilinae	<i>Myrmecophilus oregonensis</i> Bruner 1884
Acrididae	Gomphocerinae	<i>Aeropedellus clavatus</i> (Thomas 1873) <i>Ageneotettix deorum</i> (Scudder 1876) <i>Amphitornus coloradus coloradus</i> (Thomas 1873) <i>Aulocara elliotti</i> (Thomas 1870) <i>Brunneria brunnea</i> (Thomas 1871) <i>Chloealtis abdominalis</i> (Thomas 1873) <i>Chloealtis conspersa</i> (Harris 1841) <i>Orphulella pelidna</i> (Burmeister 1838) <i>Pseudochorthippus curtipennis curtipennis</i> (Harris 1835)

Family	Subfamily	Species
	Melanoplinae	<i>Pseudopomala brachyptera</i> (Scudder 1862)
		<i>Psoloessa delicatula</i> (Scudder 1876)
		<i>Asemoplus montanus</i> (Bruner 1885)
		<i>Bradynotes obesa caurus</i> Scudder 1897
		<i>Buckellacris chilcotinae chilcotinae</i> (Hebard 1922)
		<i>Buckellacris hispida</i> (Bruner 1885)
		<i>Buckellacris nuda nuda</i> (E. M. Walker 1898)
		<i>Hesperotettix viridis pratensis</i> Scudder 1897
		<i>Melanoplus alpinus</i> Scudder 1897
		<i>Melanoplus bivittatus</i> (Say 1825)
		<i>Melanoplus borealis borealis</i> (Fieber 1853)
		<i>Melanoplus bruneri</i> Scudder 1897
		<i>Melanoplus cinereus cinereus</i> Scudder 1878
		<i>Melanoplus confusus</i> Scudder 1897
		<i>Melanoplus dawsoni</i> (Scudder 1875)
		<i>Melanoplus digitifer</i> Hebard 1936 ^A
		<i>Melanoplus fasciatus</i> (F. Walker 1870)
		<i>Melanoplus femurrubrum</i> (DeGeer 1773)
		<i>Melanoplus foedus foedus</i> Scudder 1878
		<i>Melanoplus huroni</i> Blatchley 1898
		<i>Melanoplus infantilis</i> Scudder 1878
		<i>Melanoplus kennicotti</i> Scudder 1878
		<i>Melanoplus montanus</i> (Thomas 1873)
		<i>Melanoplus occidentalis</i> (Thomas 1872)
		<i>Melanoplus oregonensis oregonensis</i> (Thomas 1875)
		<i>Melanoplus packardii packardii</i> Scudder 1878
		<i>Melanoplus rugglesi</i> Gurney 1949
		<i>Melanoplus sanguinipes sanguinipes</i> (Fabricius 1798)
		<i>Melanoplus washingtonius</i> (Bruner 1885)
		<i>Oedaleonotus enigma</i> (Scudder 1876) ^A
		<i>Phoetaliotes nebrascensis</i> (Thomas 1872)
	Oedipodinae	<i>Arphia conspersa</i> Scudder 1875
		<i>Arphia pseudonietana</i> (Thomas 1870)
		<i>Camnula pellucida</i> (Scudder 1862)
		<i>Chortophaga viridifasciata</i> (DeGeer 1773)
		<i>Circotettix carlinianus</i> (Thomas 1870)
		<i>Circotettix rabula</i> Rehn and Hebard 1906
		<i>Circotettix undulatus</i> (Thomas 1872)
		<i>Conozoa sulcifrons</i> (Scudder 1876)
		<i>Cratypedes lateritius</i> (Saussure 1884)
		<i>Cratypedes neglectus</i> (Thomas 1870)
		<i>Dissosteira carolina</i> (Linnaeus 1758)
		<i>Dissosteira spurcata</i> Saussure 1884
		<i>Metator nevadensis</i> (Bruner 1905)
		<i>Pardalophora apiculata</i> (Harris 1835)
		<i>Spharagemon campestris</i> (McNeill 1901)
		<i>Spharagemon equale</i> (Say 1825)
		<i>Stethophyma gracile</i> (Scudder 1862)
		<i>Stethophyma lineatum</i> (Scudder 1862)
		<i>Trachyrhachys kiowa</i> (Thomas 1872)
		<i>Trimerotropis fontana</i> Thomas 1876

Family	Subfamily	Species
Tetrigidae	Tetriginae	<i>Trimerotropis gracilis</i> (Thomas 1872)
		<i>Trimerotropis pallidipennis</i> (Burmeister 1838)
		<i>Trimerotropis verruculata suffusa</i> Scudder 1876
		<i>Trimerotropis verruculata verruculata</i> (Kirby 1837)
		<i>Xanthippus corallipes</i> (Haldeman 1852)
		<i>Tetrix brunnerii</i> (Bolivar 1887)
		<i>Tetrix ornata occidua</i> Rehn and Grant 1956
		<i>Tetrix ornata ornata</i> (Say 1824)
		<i>Tetrix subulata</i> (Linnaeus 1758)

appear to be three taxonomic and ecological entities in BC, two of which resemble named species. Therefore, the following three names are included in the checklist to represent these three entities:

Steiroxys cf. strepens Fulton 1930: This name refers to populations found in oak woodlands on southern Vancouver Island (RBCM and UBC specimens). These populations resemble those described from western Oregon in both appearance and habitat. They do not resemble any other named species.

Steiroxys cf. trilineata (Thomas 1870): This name refers to populations found in montane to alpine meadows in the Rocky Mountains (RBCM specimens). These populations resemble those described from the southern Rocky Mountains in both appearance and habitat. They do not resemble any other named species.

Steiroxys undescribed species: This name refers to populations found in grasslands of the southern interior (RBCM, UBC, Lyman specimens). They do not resemble any named species.

Deletions from the checklist of the Orthoptera of BC

Anabrus cerciata Caudell 1907: Earlier reports of this species in BC were based on a single misidentified specimen of *A. longipes* Caudell 1907 in the Lyman Entomological Museum.

Anabrus spokane Rehn and Hebard 1920: This species had been included in previous checklists presumptively; no specimens have ever been collected in BC (but see Hypothetical/Expected species below)

Melanoplus oregonensis triangularis – Earlier reports of this species in BC were based on misidentified specimens of *Melanoplus digitifer* in the Lyman

Entomological Museum (see Additions section above).

Oecanthus nigricornis F. Walker 1869: Earlier reports of this species in BC were based on misidentified specimens of *O. quadripunctatus* Beutenmuller 1894 in the Lyman Entomological Museum.

Spharagemon collar (Scudder 1872): Earlier reports of this species in BC were based on misidentified specimens of *Spharagemon equale* (Say 1825) in the Lyman Entomological Museum.

Trimerotropis koebelei (Bruner 1889): Otte (1984) mapped this species as occurring in BC, but described the species as restricted to Oregon and California. No specimens from Canada are known, and the point on the map is assumed to be an error.

Trimerotropis sparsa (Thomas 1875): Earlier reports of this species in BC were based on a single misidentified specimen of *T. gracilis* (Thomas 1872) in the Lyman Entomological Museum.

Hypothetical/ Expected species

The following species are excluded from the BC checklist for lack of unequivocal evidence of either their presence in the province or the taxonomic validity of the species. Some of these species are likely to be confirmed as occurring in BC in the future.

Anabrus spokane Rehn and Hebard 1920: Recorded in northern Idaho and adjacent Washington and may occur in the Creston or Trail areas. However, the original description of this species did not clearly separate it from *A. longipes*, and it may be a synonym.

Brunneria yukonensis (Vickey 1969): This species has been recorded in the southwestern Yukon Territory and may occur in adjacent BC.

Conozoa texana Bruner 1889: Reported by Otte (1984) to occur in BC. The only known

Canadian specimens could not be unequivocally identified and may represent *C. sulcifrons* (Scudder 1876) (Vickery 1987).

Encoptolophus costalis (Scudder 1862): The species has been recorded in the Peace region of Alberta and may occur in adjacent BC.

Melanoplus dodgei (Thomas 1871): This species has been recorded in northern Montana and may occur in the southern part of the British Columbian Rocky Mountains.

Melanoplus frigidus (Boheman 1846): This species has been recorded in coastal Alaska and may occur in extreme northwestern BC.

Melanoplus gladstoni Scudder 1897: This species has been recorded in grasslands of western Alberta and may occur in BC in the southern Rocky Mountains or the Peace Region.

Melanoplus packardii brooksi Vickery 1979: This taxon has been recorded in northern Alberta and may occur in adjacent BC.

Myrmecophilus manni Schimmer 1911: An unidentified *Myrmecophilus* species was collected once near Penticton (specimen at Beatty Biodiversity Museum) and photographed once in Oliver (Iowa State University 2003–2012). These specimens resemble *M. oregonensis* Bruner 1884 morphologically. However, *M. oregonensis* is not known to occur east of the Cascade Mountains (Hebard 1920). The range and habitat for these records are most consistent with published information on *M. manni* (Hebard 1920).

Phlibostroma quadrimaculatum (Thomas 1871): This species has been recorded in western Alberta and may occur in adjacent BC.

Pristoceuthophilus gaigei Hubbell 1925: This species was removed from BC checklists

following a suggestion by Hubbell (1985) that it is a synonym of *P. cercalis* Caudell 1916. *P. gaigei* is retained here as a hypothetical species because it has never been formally entered into synonymy with *P. cercalis*.

Tessalana tessellata tessellata (Charpentier 1825): This European species was introduced to California (Rentz 1963) and has rapidly spread as far north as the mid latitudes of Washington on both sides of the Cascades (pers. obs.). It is expected to eventually spread into BC in the lower mainland and/or Okanagan Valley.

Trimerotropis cincta (Thomas 1870): Reported by Otte (1984) to occur in BC, but shown as disjunct from the remainder of the species' range. The only known Canadian specimens could not be unequivocally identified, and may represent *T. fontana* (Thomas 1876) (Vickery 1987).

Xanthippus aquilonius Otte 1984: This species was described based on specimens from the Okanagan and Kettle Valleys in BC. However, previous authors have commented on the apparent overlap with *X. coralipes* (Vickery 1987, Vickery and Scudder 1987). *X. aquilonius* is omitted from the checklist with the assumption that it will eventually be synonymised with *X. coralipes*.

Xanthippus brooksi Vickery 1967: This species has been recorded in the southwestern Yukon Territory and may occur in northwestern BC.

Adventive species

A number of foreign species of Orthoptera have been recorded in BC as rare adventives that have not become established and are not a part of the BC fauna. These species are not included in the checklist. Records of adventive species can be found in Vickery and Kevan (1985) and Vickery and Scudder (1987).

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Changes in the Status and Distribution of the Yellow-faced Bumble Bee (*Bombus vosnesenskii*) in British Columbia

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ABSTRACT

Bombus vosnesenskii, the distinctively-patterned Yellow-faced Bumble Bee, has undergone a significant and rapid range extension in British Columbia. Known initially from a single record of a few specimens at Osoyoos in 1951, it was put forward in 1996 as a species that warranted a threatened or endangered status because of its severely restricted range in the province. However, since 2000, the species has expanded north in the Okanagan Valley, west to the Similkameen Valley and, especially, has become firmly established in south coastal regions of the province, including Vancouver Island. Population increases in *B. vosnesenskii* to the south of BC have also been reported. The reasons for the rapid expansion of *B. vosnesenskii* in BC are unclear. Particularly in lowland southwestern BC, the range expansion might have been enhanced through escapes from colonies kept as pollinators of agricultural crops. The spread of *B. vosnesenskii* has coincided with the decline of *B. occidentalis*, so the former may have been introduced or naturally expanded its range at the same time as a niche was becoming vacant. Recent changes in agricultural practices, such as the increase of cranberry crops, may also be a factor, as might climate warming. Clarification of the reasons for the rapid population increases and range expansion of *B. vosnesenskii* is needed but, in the meantime, it should no longer be considered a candidate for species-at-risk listing.

Key Words: Hymenoptera; Apidae; Bombus; *Bombus vosnesenskii*; range expansion; British Columbia

INTRODUCTION

Trends in pollinator populations are most frequently reported as declines, and the range of causes include habitat loss, disease, pesticides, climate change and competition with invasive species (Goulson *et al.* 2008, Potts *et al.* 2010, Cameron *et al.* 2011). At a time when several species of North American bumble bees are becoming increasingly endangered (e.g., *Bombus occidentalis* Greene), others are exhibiting the opposite trend (Cameron *et al.* 2011, Colla and Ratti 2010).

Bombus vosnesenskii Radoszkowski, the distinctively-patterned Yellow-faced Bumble Bee, has undergone a significant and rapid range expansion in British Columbia (BC). This species can be readily recognized by its bold coloration: setae on the face, front of the

thorax and a band on the fourth abdominal tergum are bright yellow; the remainder of the bee is covered by black setae (including all sternal segments) and the wings are dark brown (Fig. 1). In the Pacific Northwest, there are two similar-looking species, *Bombus caliginosus* (Frison) and *Bombus vandykei* (Frison). *Bombus caliginosus* has been reported only as far north as the Olympic Peninsula and Okanogan Valley in Washington State (Krombein *et al.* 1979) and we are aware of only a single photographic record of a male *B. vandykei* from BC (E-Fauna 2012). *Bombus vosnesenskii* is so readily recognizable, it is unlikely that any significant populations were previously overlooked in BC, and, instead, the dramatic increase in observations and collections documented in this paper represent

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a real change in the species' range and abundance in the province.

Bombus vosnesenskii ranges from southern BC south through Washington, Oregon, western Nevada and California to northern Baja California in Mexico (Thorp *et al.* 1983). Stephen (1957) noted that the bee was abundant in the coastal valleys and mountains of California and Oregon, but uncommon along the coast of southwestern Washington, Oregon and northern California. There it was mostly replaced by *B. caliginosus*. Around San Francisco Bay and Puget Sound, however, *B. vosnesenskii* was the more common of the two. Also, at that time, the bee was scarce north of the Columbia River and east of the Cascade Range and there were no records from eastern Washington or Idaho (Stephen

1957). For many years in BC, *B. vosnesenskii* was known from a single record of a few specimens collected at Osoyoos in 1925 (Buckell 1951) and, in 1994 and 1996 Scudder suggested that the severely restricted BC range warranted a threatened or endangered status for the species. At that time, he was unaware of the first known coastal BC specimen, a surprisingly early 1970 record from Burnaby in the Simon Fraser University collection. However, since 2000, the species has expanded north in the Okanagan Valley, west to the Similkameen Valley and, especially, has become firmly established in south coastal regions of the province. In many of these newly occupied areas, it is now among the most commonly noted bumble bee species.

MATERIALS AND METHODS

Data were collected from adult specimens of *Bombus vosnesenskii* from the collections of the Royal British Columbia Museum, Victoria, BC (RBCM); Department of Biological Sciences, Simon Fraser University, Burnaby, BC (SFU); Beaty Biodiversity Museum, University of BC, Vancouver, BC (UBC); and the Packer Collection, Biology Department, York University, Toronto, ON (PCYU). Photographic records were compiled from postings on the web sites indicated. In most cases, specimens were identified by the

collectors and vetted by experts. Specimens with an asterisk were identified by the authors.

CANADA: BRITISH COLUMBIA: Abbotsford, blueberry farm, 49.130992N 122.260036W, 4.vi.2011, L. Button (1♀, SFU 741525), 49.718425"N 122.388556W, 12.vi.2011, L. Button (1♀, SFU 741644), 49.126239N 122.418817W, 12.vi.2011, L. Button (1♀, SFU 741742); Burnaby, 1.viii.1970, J. Hicks (1♂, SFU), 10.x.2007, S. Lam (1♂, SFU), 10.ix.2009, B. Rajala (1♂, SFU); 15.x.2009 K. Lee (1♂, SFU); Cawston, Forbidden Fruit Winery, 14.vii.2010, D.



Figure 1. *Bombus vosnesenskii* queen. BC, Victoria, 48.414722N 123.325111W, 27 April 2012, R.A. Cannings, RBCM ENT012-0022860.

Marks (1♀, RBCM); Duncan, Mount Tzuhalem Ecological Reserve, 48.78617N 123.63399W, 7.v.2010, E. Elle, L. McKinnon (3♀, SFU 726540, 727653, 727660), Quamichan Lake, Cowichan Garry Oak Reserve, 48.808556N 123.631250W, 14.v.2009, E. Elle (1♀, SFU 719624), 3.v.2010, G. Gielens (1♀, SFU 726491); Fraser Valley Regional District, Onnink property, 49.07833N 122.38778W, 6.v.2004, C. Ratti (1♀, PCYU), Randhawa property, 49.12806N 122.41806W, 22.v.2003, C. Ratti (1♀, PCYU), 28.v.2003, C. Ratti (1♀, PCYU); Greater Vancouver Regional District, Banns property, 49.22361N 122.75333W, 19.vi.2003, C. Ratti (1♀, PCYU), 1.vii.2003, C. Ratti (1♀, PCYU), 5.vii.2003, C. Ratti (2♀, PCYU), 17.vi.2004, C. Ratti (1♀, PCYU), Bissett property, 49.08833N 123.16388W, 16.iv.2004, C. Ratti (1♀, PCYU), Edwards property, 49.14778N 123.06528W, 26.vi.2003, C. Ratti (1♀, PCYU), 4.vii.2003, C. Ratti (1♀, PCYU), 8.vii.2003, C. Ratti (1♀, PCYU), 12.vii.2003, C. Ratti (5♀, PCYU), Fisher property, 49.14472N 123.07333W, 17.iv.2003, C. Ratti (1♀, PCYU), 4.vi.2003, C. Ratti (1♀, PCYU), .iv.2004, C. Ratti (1♀, PCYU), 9.iv.2004, C. Ratti (2♀, PCYU), 21.v.2004, C. Ratti (2♀, PCYU); Hopcott property, 49.24972N, 122.71722, 5.vii.2003, C. Ratti (1♀, PCYU), Mayberry property, 49.19250N, 123.04556, 26.vi.2003, C. Ratti (2♀, PCYU), 26.vi.2003, C. Ratti (1♀, PCYU), 4.vii.2003, C. Ratti (1♀, PCYU), 12.vi.2004, C. Ratti (1♀, PCYU), 17.vi.2004, C. Ratti (6♀, PCYU), 22.vi.2004, C. Ratti (2♀, PCYU), McKim property, 49.08139N 123.12056, 30.iv.2003, C. Ratti (2♀, PCYU), 23.iv.2004, C. Ratti (1♀, PCYU), 14.v.2004, C. Ratti (2♀, PCYU); Surrey farms property, 49.09833N 122.79194W, 8.v.2003, C. Ratti (1♀, PCYU), 11.v.2003, C. Ratti (1♀, PCYU), 1.vi.2003, C. Ratti (1♀, PCYU), Tilson property, 49.15611N 122.43389W, 24.vi.2004, C. Ratti (1♀, PCYU); Lake Cowichan, 15 km E, Stoltz Meadows, 48.781667N 123.885250W, 17.v.2009, L. McKinnon (1♀, SFU 717264), Mesachie Lake, Cowichan Lake Forestry Station, 48.81885N 124.1381885W, 23.vi.2009, E. Elle (1♀, SFU 719077); Okanagan Falls, Blasted Church Vineyards, 3.vi.2010, D. Marks (1♀, RBCM), Blue Mountain Vineyards, 23.vi.2010, D. Marks (1♀, RBCM); Osoyoos, 20.vii.1925, E.R. Buckell

(2♀, UBC); Pitt Meadows, blueberry farm, 49.260858N 122.701900W, 23.v.2011, L. Button (1♀, SFU 741145), 49.26092N 122.70444W, 5.vi.2011, L. Button (1♀, SFU 741341); Richmond, blueberry farm, 49.152308N 123.072550W, 5.vi.2011, L. Button (1♀ RBCM 012-000783); Vancouver, 16.ix.2006, E. Xia (1♂, SFU), 15.ix.2009, M. Sighan (1♂, SFU), Jericho Park, 30.vi.2011, S.A. Russell (1♀, UBC), Queen Elizabeth Park, 6.x.2006, D. Tanner (1♀, SFU), Stanley Park, 14-22.v.2008, J.A. McLean & A. Li (1♀, UBC), University of BC, Beaty Museum, 22.v.2010, R.T. Curtiss (2♀, UBC); 17.vi.2010, R.T. Curtiss (2♀, UBC), University of BC Botanical Gardens, 24.vi.2011, S.A. Russell (3♀, UBC); 5.vii.2011, S.A. Russell (2♀, UBC); 8.vii.2011, S.A. Russell (2♀, UBC); 19.vii.2011, S.A. Russell (1♀, UBC), University of BC, Pacific Spirit Park, 3.vi.2010, R.T. Curtiss (1♀, UBC); Victoria, Beacon Hill Park, 48.409715N 123.362835W, 20.vi.2007, L. Neame (1♀, SFU 709157); 48.409715N 123.362835, 20.vi.2007, L. Neame (1♀, SFU 709175); 48.409715N 123.362835W, 10.v.2007, L. Neame (1♀, SFU 709195); 48.409715N 123.362835W, 12.vi.2007, L. Neame (1♂, SFU 709263); Victoria, 32 Chown Place, 17.iv.2010, M. Walsh (1♀, RBCM ENT012-002855*); Victoria, Oak Bay, Costain Green, 48.452754N 123.301117W, 8.vi.2007, L. Neame (1♂, SFU 709570); Victoria, Saanich, Royal Oak Drive, found dead, 14.vii.2011, C.R. Copley (1♀, RBCM ENT012-002856), Beaver Lake, Retriever Ponds, 17.vii.2011, C.R. Copley (1♀, RBCM ENT012-002859), Cedar Hill Park, 48.458103N 123.347128W, 7.v.2007, L. Neame (1♀, SFU 709464), Little Saanich Mountain, 48.520446N 123.420315W, 10.v.2007, L. Neame (1♀, SFU 710398), Lochside Trail, found dead, 13.iv.2012, C.R. Copley (2♀, RBCM ENT012-002857, -002858), Prospect Lake, 25.v.2005, D.F. Fraser (1♀, RBCM ENT012-005340); Victoria, 1909 Shotbolt Road, 48.414550N 123.326210W, 27.iv.2012, R.A. Cannings (1♀, RBCM ENT012-0022860); Victoria, University of Victoria, 14.ix.2009, C. Bruckal (1♂, RBCM ENT012-002852*), L. Dumoulin (1♂, RBCM ENT012-002853*), 21.ix.2009, R. Pretty (1♂, RBCM ENT012-002854*); Victoria, View Royal, Thetis Lake Regional Park,

48.466917N 123.466278W, 29.vi.2005, E. Elle (1♂, RBCM 012-000784).

Identifiable photographs of *B. vosnesenskii* from BC are also available. On the E-Fauna BC (2012) website, photos are posted from Crescent Beach, Nanaimo, Port Alberni,

Richmond, Saanichton, and Vancouver. The Crescent Beach photo (#10577), from 14 July 2007, is the earliest taken. Flickr (2012) has identifiable photos from Vancouver but the BugGuide website (2012) has no BC photographs.

RESULTS AND DISCUSSION

The present known range of *Bombus vosnesenskii* in BC is shown in Fig. 2. Winston and Graf (1982) and MacKenzie and Winston (1984) reported on bee diversity in surveys of both commercial berry crops and native vegetation in the Fraser Valley in 1981 and 1982, but did not record *B. vosnesenskii*. However, of 2248 bumblebees collected, 25 were identified as “other” in MacKenzie and Winston, and could potentially have included *B. vosnesenskii*. The earliest record for the southwest coast of BC is from Burnaby in 1970; no others are known until 2000. Since then, the bee has been recorded frequently throughout the Lower Mainland. In

2000-2001, Tommasi *et al.* (2004) reported 38 individuals in urban surveys throughout Greater Vancouver. This compared to 801 *B. flavifrons* Cresson, 547 *B. mixtus* Cresson, 194 *B. melanopygus* Nylander, 16 of unknown species and 2 *B. occidentalis*, making *B. vosnesenskii* one of the less common species of the region. Ratti *et al.* (2008), in a crop pollination study in the Fraser Valley in 2003-04, found the species at 10 of 11 blueberry and cranberry fields surveyed. It was at the time still one of the less common *Bombus* species, comprising 39 of the 3,683 specimens collected. The bee was observed at all 15 sites surveyed at farms in the Fraser

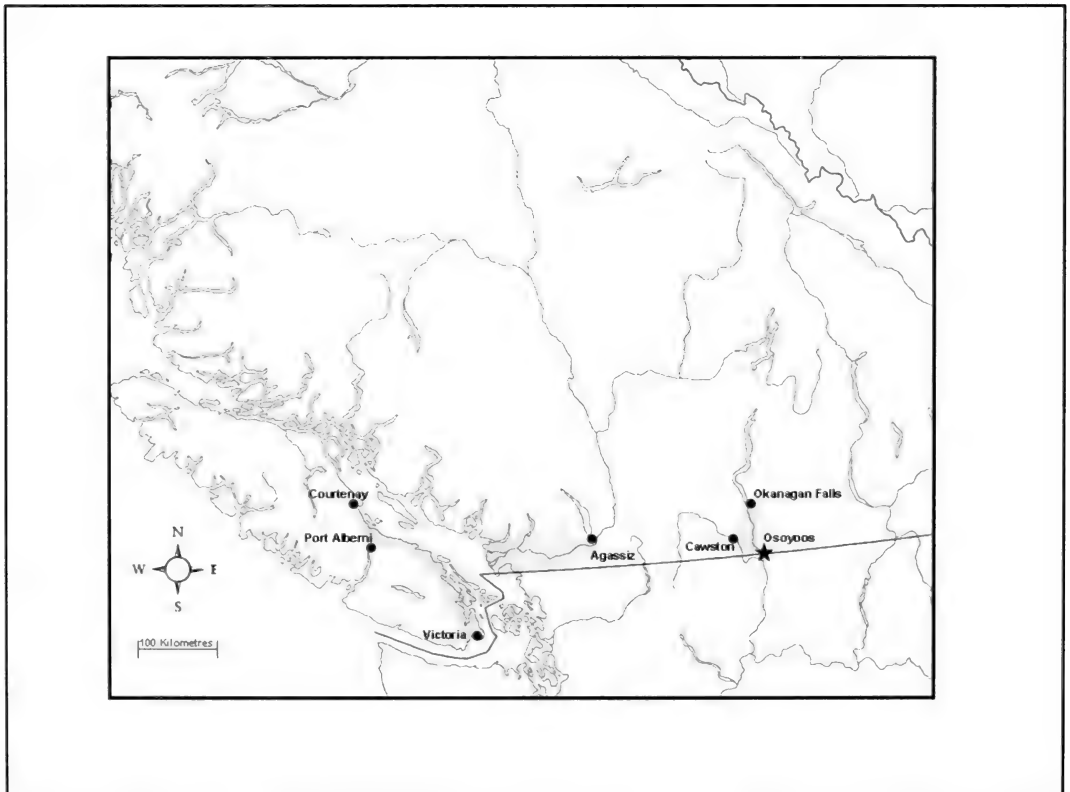


Figure 2. Map of southwestern British Columbia illustrating range expansion of *Bombus vosnesenskii*. Shaded area represents 2012 range. The symbol ★ represents the original 1925 record at Osoyoos.

Valley between 17 July and 21 September 2009 (Bains *et al.* 2009) and, by 2010, when they documented the bee in 25 of 64 sites surveyed from Delta east to Agassiz, Parkinson and Heron (2010) could state that it was one of the most common late season *Bombus* species in Greater Vancouver and the Fraser Valley.

Also in 2010, similar pollinator surveys in the South Okanagan and Similkameen valleys recorded *B. vosnesenskii* at three farms from Okanagan Falls south to Cawston (Marks and Heron 2010), the first records in the Interior since Buckell's initial collections in 1925. However, population expansion in the Okanagan has been much less obvious than on the South Coast. Other surveys in 2010 in the grasslands of the South Okanagan, in which about 10,000 pollinating insects were collected, recorded no *B. vosnesenskii* specimens (Elwell 2012). In 2012 we asked a number of biologists and naturalists throughout the Okanagan to watch for the distinctive species, but none were seen.

On Vancouver Island the Yellow-faced Bumble Bee is well established and expanding its range. In 1951 Buckell intimated that *B. vosnesenskii* could occur in Victoria; nevertheless, the first specimen record on the Island is from near Prospect Lake, Saanich, on 25 May 2005. Another specimen was collected the same year on 29 June at Thetis Lake Regional Park, during the third author's pollination research there. That year, she and her students pan-trapped at eight sites from Victoria to Campbell River and caught no other individuals. In 2007 they sampled with nets and pans at 19 sites on the Saanich Peninsula and collected seven specimens, out of 884 *Bombus* collected (less than 1%). In a net-only survey in the same area in 2012, 301 out of 2139 *Bombus* collected (14%) were *B. vosnesenskii*. In the Cowichan Valley in 2009, three were captured at three sites; in 2010 in the same region, four were collected at two localities. By 2009 the species was found as far north on the Island as Port Alberni (E-Fauna BC: photo #12718) and in 2012 it was photographed in Courtenay (T. Thormin, pers. comm.). *Bombus vosnesenskii* is now among the most common bumble bee species on the south coast of BC, especially in urban and farmland habitats.

Population increases in *B. vosnesenskii* to the south of BC have also been reported. In Oregon, Thorp (2008) conducted surveys for *Bombus franklini* (Frison) from 1998 to 2007 and noted that more than 50% of all *Bombus* reported in 2006 and 2007 were *B. vosnesenskii*, up from approximately 30% in 1998. Cameron *et al.* (2011) noted that *B. vosnesenskii* populations are stable in the western United States relative to historic data, at a time when several other *Bombus* species are declining.

The reasons for the rapid expansion of *B. vosnesenskii* in BC are unclear. One possibility, particularly in lowland southwestern BC, is that the bee could have been assisted in its range expansion through escapes from colonies kept as pollinators of agricultural crops. In 1991, *B. vosnesenskii* was tested as a greenhouse pollinator of tomatoes in Surrey south of Vancouver, although it was not intentionally released during that study (Dogterom *et al.* 1998). In adjacent Washington State, colonies are currently commercially available for crop pollination of raspberries, blueberries, cranberries, strawberries, peaches, plums, cherries and cabbage (Mike Juhl, pers. comm., <http://www.hornetnestsfreeremoval.com/29601.html>). Bumble bee escapes from greenhouses are well documented elsewhere, have contributed to the out-of-range introductions of other *Bombus* species, and have been implicated in the introduction of bumble bee diseases (Velthuis and van Doorn 2006, Colla *et al.* 2006). Greenhouse escapes likely resulted in the introduction of *B. vosnesenskii* to Australia (Planck 1999).

In BC the spread of *B. vosnesenskii* has coincided with the decline of *B. occidentalis* (Colla and Ratti 2010), so the former may have been introduced or naturally expanded its range at the same time as a niche was becoming vacant. As a study by Allen *et al.* (1978) showed, *B. vosnesenskii* has large colonies (including, in one, an estimate of the production of 650 queens), implying that it has an impressive capacity for colonization. Cameron *et al.* (2011) reported that *B. vosnesenskii* has a greater genetic diversity and a lower prevalence of the fungal pathogen *Nosema bombi* Fantham and Porter, compared to *B. occidentalis*, suggesting that these characteristics could serve as predictors of

population patterns. It is unknown, however, whether these observations indicate cause and effect, or if they apply to BC.

Recent changes in agricultural practices may also be a factor. Declines in some species of bumble bees have been attributed to the intensification of agriculture (Goulson *et al.* 2008), and even *B. vosnesenskii* populations have been shown to be closely linked to the proximity of natural habitat (Greenleaf and Kremen 2006). But *B. vosnesenskii* is frequently reported pollinating cultivated cranberries in Oregon, and in BC this industry has undergone considerable expansion in recent years. There are currently 1150 hectares under cranberry production, particularly in the Fraser Valley, as well as a few operations on Vancouver Island (Ministry of Agriculture 2012).

Modest population expansion in the South Okanagan-Simikameen, where we can find no reports of pollinator introductions, suggests that a natural cause is at work there. A number of species across a wide variety of taxa show changes in their distributions due to the effects of climate warming (Parmesan 2006, David and Handa 2010, Feeley 2012, Moreno-Rueda *et al.* 2012). Their life histories make insects especially good at adapting quickly to changes in the environment (Robinet and Roques 2010), so the spread of *B. vosnesenskii* may be facilitated by anthropogenic climate change.

Clarification of the reasons for the rapid population increases and range expansion of *B. vosnesenskii* is needed but, in the meantime, it should no longer be considered a candidate for species-at-risk listing.

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Identification of feeding stimulants for Pacific coast wireworm by use of a filter paper assay (Coleoptera: Elateridae)

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ABSTRACT

Sugars and several plant essential oils were evaluated as feeding stimulants for larvae of Pacific coast wireworm, *Limoniuss canus* (Coleoptera: Elateridae). Compounds were evaluated by quantifying biting rates of wireworms on treated filter paper disks, modifying a method used previously in assays with *Agriotes* spp. wireworms. Independent counts of the same disk showed that the method led to repeatable estimates of biting rate. Higher rates of biting were obtained on filter paper disks if those disks had been treated with sucrose, fructose, glucose, maltose, and galactose, than if the disks were left untreated. Sucrose and fructose were more stimulatory than the other three sugars. Biting rates declined with decreasing concentrations of sugars in water. Combining a highly stimulatory sugar (sucrose) with certain plant essential oils in some cases led to non-additive (both synergistic and antagonistic) effects on biting rates. We discuss the possible role for this type of assay in developing insecticide-laced baits for attract-and-kill programs.

Key Words: *Limoniuss canus*, feeding assay, phagostimulants, synergism, plant essential oils

INTRODUCTION

Wireworms (Coleoptera: Elateridae) are important subterranean pests in a number of vegetable and grain crops worldwide. The Pacific coast wireworm, *Limoniuss canus* LeConte, inhabits irrigated soils of western North America, where it is a pest in potatoes, vegetables, and grain crops (Lane and Stone 1960). Grower difficulties in managing this and other wireworm pests can be attributed to a number of factors, including a shortage of chemicals effective against wireworms, lack of efficient monitoring tools, and incomplete understanding of wireworm basic biology (Jansson and Seal 1994).

Wireworm larvae are attracted to various types of food-based baits, including baits composed of germinating seed; wheat and rice flours; and rolled oats (Apablaza *et al.* 1977; Toba and Turner 1983; Horton and Landolt 2002). Historical success in drawing wireworms to food-based baits under field conditions has prompted efforts, beginning at least as early as the 1930s, to develop insecticide-laced baits for use in wireworm control (Lehman 1933; Woodworth 1938). Yet, almost 80 years following these first efforts, no toxicant-laced bait is commercially available for controlling wireworms in North

America. Difficulties in developing field-effective baits may often be due to wireworm behavior. Specifically, a bait that is highly attractive when free of a toxicant may become repellent to wireworms with addition of a toxicant (Lehman 1933; Woodworth 1938). Similar problems may affect how well coating of grain seed with insecticide protects germinating seed from wireworms. Protection of treated seed from wireworm damage may often be due to pre- or post-contact repellency of the insecticide rather than to actual kill of the pest (Long and Lilly 1958; van Herk and Vernon 2007; Vernon *et al.* 2009).

A long-term aim of our research program is to develop a toxicant-laced bait that can be used in an attract-and-kill program for managing *L. canus*. Ongoing trials with a food-based bait laced with an insecticide (formulation currently proprietary) have shown mixed results: rates of kill in laboratory trials are inconsistent, apparently due in part to antifeedant effects associated with presence of the toxicant (DRH pers. obs.). Improving bait palatability by the addition of feeding stimulants could lead to increased rates of kill if the stimulant prompts higher rates of feeding even in the presence of the toxicant.

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Compounds that elicit increased feeding by *Limoni* wireworms have yet to be specifically identified and assayed, and this has slowed our efforts to develop a consistently effective bait.

The objective of this study was to develop an assay method suitable for testing compounds as potential feeding stimulants for *L. canus*. Assays to determine whether certain compounds prompt feeding behaviour of subterranean insects generally involve application of test products to a substrate that allows feeding by the insect. We modified a filter paper assay developed over 50 years ago to examine biting response of *Agriotes* spp. wireworms (Thorpe *et al.* 1947; Crombie and Darrah 1947), and determined whether the method would be suitable for identifying compounds that elicit feeding of *L. canus*. We

then used this assay method to examine biting rates of *L. canus* in response to several sugars at different concentrations. Sugars have been shown to prompt feeding by a number of root-feeding insects (e.g., Thorpe *et al.* 1947; Allsopp 1992; Bernklau and Bjostad 2008), and may be stimulatory enough under some conditions to reduce the deterrent effects of otherwise repellent chemicals (Shields and Mitchell 1995; Bernklau *et al.* 2011). We next tested whether one particular sugar (sucrose) in combination with other plant compounds acted synergistically with those compounds in eliciting the biting response. We examined combinations of several plant essential oils with sucrose, as plant essential oils have been shown to both deter and elevate feeding by phytophagous insects (Tanton 1965; Klepzig and Schlyter 1999).

MATERIALS AND METHODS

Source of insects. Mid-sized to large larvae (1.2–1.4 cm in length) of *L. canus* were collected in spring from fields located near Yakima, WA and Hermiston, OR. The insects were collected by baiting with balls of moistened rolled oats (Horton and Landolt 2002). The Yakima field was fallow at the time of baiting, but had been planted to either wheat or potato crops in preceding years. Wireworms at the Hermiston site were collected along a fence line adjacent to potato or wheat crops. Larvae were stored in groups of 20–30 in 35 x 25 x 10 cm plastic tubs filled with moistened potting soil until they were used in the assays. Tubs were kept at room temperature (22–23°C). Small plugs of moistened rolled oats were added to each tub every 7–10 d, and removed after 48 h; otherwise, the larvae were kept unfed. Larvae were used within 1–3 weeks of having been collected. Assays were done in May and June of 2009 and 2012. Wireworms were discarded following each assay.

Quantification of biting response.

Feeding response was assayed by quantifying biting marks of wireworms on treated filter paper disks (Thorpe *et al.* 1947; Crombie and Darrah 1947). Filter paper disks (Grade 413 qualitative filter paper, 5.5 cm diameter; VWR Scientific Products, West Chester, PA) were treated with individual compounds or with combinations of compounds (see below) and

presented to wireworms in either paired-choice or no-choice assays. The treated disks were placed in plastic petri dishes (14.5 cm diameter x 2 cm deep) filled with 200 ml of sand (Quikrete Premium Playground Sand, Quikrete, Atlanta, GA) moistened with 30 ml of tap water. In positioning a treated disk in the petri dish, we first filled each dish approximately one-quarter full with the moistened sand and placed the disk on the surface of the sand. The disk was then covered with enough additional sand to fill the petri dish approximately three-quarters full. Wireworms (see below for numbers used in each assay) were placed on the surface of the sand layer at the center of each petri dish and allowed to enter the soil. The insects were randomly assigned to treatments, to ensure that any variation in feeding rates associated with wireworm size was randomly allocated across the different treatments. The assays were conducted at room temperature. Petri dishes were kept covered to prevent the sand from drying.

After 24 h of exposure to wireworms, disks were examined for feeding damage. In studies with *Agriotes sputator* (L.), *Agriotes lineatus* (L.), and *Agriotes obscurus* (L.) (Thorpe *et al.* 1947; Crombie and Darrah 1947), the stimulatory response was quantified by counting bite marks on the disks. However, we found that it was often difficult to

determine where physically on a disk a given bite mark began and ended, which made this method somewhat subjective. This approach was especially problematic when highly stimulatory products were tested, as these products often led to large contiguous patches of damage on disks. Instead, we quantified biting rates on a disk by placing the disk on a light table, covering it with a transparent grid (0.5 x 0.5 cm squares), and then counting the number of squares in which any bite marks were observed (Fig. 1). Both sides of each disk were examined. Squares in which the feeding damage was observable on both sides of the filter paper disk were counted only once. Two people examined each disk, and an average of the two counts was used in the data summary and analyses. To examine repeatability of this method for estimating biting rates, correlation analysis was used to determine whether counts were consistent between the two people. The assessments of repeatability were done using the PROC CORR program in SAS (SAS Institute 2010).

(1) Sugars as feeding stimulants. Five sugars were assayed: D-sucrose, D-fructose, D-glucose, D-maltose, and D-galactose (Sigma-Aldrich, St. Louis, MO). Each sugar was tested at five concentrations in deionized water: 2% (2 g per 100 ml of water), 1%, 0.5%, 0.25%, and 0.125%. Each filter paper disk received 200 μ l of solution delivered by pipette, which led to quantities of sugar per disk between 4 mg (2% solutions) and 0.25 mg (0.125% solutions). Control disks received an equivalent amount of deionized water. Disks were assayed immediately following treatment. We used a choice test to examine

feeding stimulation, by pairing a treatment and control disk in our feeding arenas (as in Wensler and Dudzinski 1972). Paired disks were set 1 cm apart in the petri dish and buried in sand as described above. Each paired comparison was replicated 10 times. Three wireworms were used per feeding arena, and allowed to feed for 24 hrs.

For each pair of disks, we subtracted control results (number of grid squares showing feeding damage) from treatment disk results. Thus, large positive values indicate that the sugar was highly stimulatory, whereas values near zero indicate that damage was similar on sugar-free and sugar-treated disks. These arithmetic differences were then used in a two-way factorial analysis of variance to assess the effects of sugar type and sugar concentration on biting response. A Tukey-Kramer means separation test was used to compare sugars following a significant ANOVA. To test whether a particular sugar at a specific concentration was significantly stimulatory, we compared simple effects means (i.e., a specific sugar at a specific concentration) to a hypothesized value of zero, using a t-statistic. Thus, a mean found to be significantly larger than zero was evidence that the sugar at that particular concentration was stimulatory. Analyses were done with the PROC GLIMMIX program in SAS (SAS Institute 2010).

(2) Additive and non-additive effects of sucrose and plant essential oils. These trials were done to determine whether our filter paper assay could be used to demonstrate non-additive (synergism or antagonism) effects of plant essential oils if combined with a sugar.

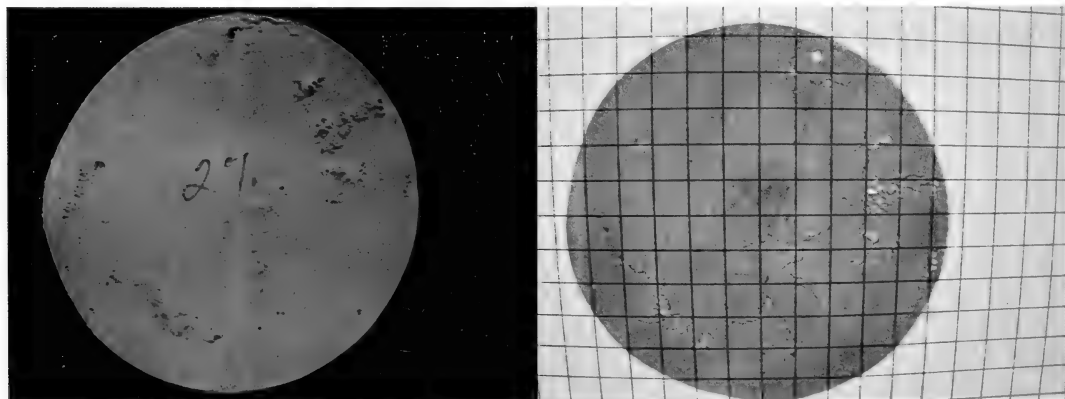


Figure 1. Sucrose-treated disk showing feeding damage (left photograph), and the same disk on light box showing grid (0.5 x 0.5 cm squares) used in quantifying damage (right photograph).

We examined five plant essential oils in the presence and absence of sucrose: lemon (*Citrus limon*), garlic (*Allium sativum*), winter savory (*Satureja montana*), cedarwood (*Juniperus virginiana*), and tea tree (*Melaleuca alternifolia*) (Herbal Advantage, Rogersville, MO; Mountain Rose Herbs, Eugene, OR). These compounds were chosen because preliminary trials suggested that a range of effects (synergistic to antagonistic) would be produced when the compounds were used in combination with a sugar. Sucrose was chosen for these trials because this sugar was found in our assays with sugars to elicit substantial rates of biting (see Results).

The literature of insect feeding trials is not always consistent in how synergism and antagonism are defined and demonstrated. We used an experimental design that allowed us to statistically demonstrate either of these two effects as the interaction term in a factorial analysis of variance. The design was a 2 x 2 (sucrose x plant oil) factorial experiment in which sucrose was at one of two levels (present vs. absent) and the plant essential oil of interest was at one of two levels (present vs. absent). Thus, unlike the previous trial with sugars, this assay was done using a no-choice design having (for a given plant oil) four possible treatments. A significant interaction term in the analysis of variance would be evidence of non-additive effects: i.e., biting rate in the combined sucrose + plant oil treatment was either higher (synergism) or lower (antagonism) than the sum of their separate effects.

All plant oils were diluted in solvent as 10 mg of the product in 100 ml of methylene chloride. Sucrose was diluted to 0.2% in deionized water. In preliminary trials, we found that wireworms often failed to feed on

disks that were free of both sucrose and the plant oil, which led to difficulties in conducting analysis of variance tests (due to variance assumptions of ANOVA). Therefore, we redefined our two sucrose levels (i.e., present vs. absent) as sucrose present (0.2%) versus sucrose highly dilute (0.02%), thus substituting an extremely dilute level of sucrose for our no-sucrose level. This highly dilute level of sucrose prompted some biting by wireworms, and this in turn allowed us to use ANOVA to examine results.

Filter paper disks were first treated with 200 μ l of the diluted plant oil in methylene chloride or with 200 μ l of methylene chloride (for those treatments in which plant oil was not present). Disks were allowed to dry, and then were treated with 200 μ l of the appropriate sucrose solution (either 0.2% or the highly dilute solution). The disks were immediately placed singly in moistened sand and petri dishes as described above for the sugar trials. A single wireworm was added to each petri dish and allowed to feed for 24 h. At the end of 24 h, biting rates (numbers of squares showing damage) were quantified for each disk using methods described above. We had 20 replicates of each treatment.

Number of squares showing damage was compared among treatments using ANOVA for a 2 x 2 factorial design. If the interaction term was significant, we examined interaction graphs to assess whether biting rates in the combination treatment were higher than expected under an additive model (synergism) or lower than expected under an additive model (antagonism), and used the PDIFF command in SAS to examine comparisons of simple effects means (e.g., plant oil effects separately at each level of sucrose).

RESULTS

(1) Sugars as feeding stimulants. Estimates of biting rates (= numbers of squares showing damage) were highly correlated between the first count and second count (Fig. 2; data shown only for the sucrose-treated disks), suggesting that our counting method provided an objective and quantifiable index of biting rates. We observed biting marks in virtually all replications, except at the most dilute rate (Fig. 2). All five sugars

prompted biting by *L. canus* (Fig. 3); each mean is the average of the arithmetic differences in grid squares showing damage, between the paired sugar-treated and control disks. Both concentration ($F_{4,225} = 11.8$, $P < 0.0001$) and type of sugar ($F_{4,225} = 28.9$, $P < 0.0001$) affected biting rates. The sugar x concentration term was non-significant ($P = 0.28$). A means separation test showed that sucrose was significantly more stimulatory

than fructose, and that both products prompted more biting than glucose, maltose, and galactose (Fig. 4; the latter three sugars were statistically the same in their effects). Stimulatory effects disappeared at concentrations of 0.125% for fructose, and at 0.5% for glucose, maltose, and galactose (assessed using *t*-tests to compare each mean in Fig. 3 to zero); all concentrations of sucrose were stimulatory.

(2) **Additive and non-additive effects of sucrose and plant essential oils.** Results with the five plant essential oils are shown as a series of interaction graphs (Fig. 5), in which (+) indicates presence of the compound and (-) indicates that the compound is absent (plant oil) or is at a highly dilute concentration (sucrose at 0.02%). Additive (Fig. 5A), synergistic (Fig. 5BC), and antagonistic (Fig. 5DE) effects were each observed. Winter savory elicited biting responses whether in the presence or absence of sucrose (main effects of plant oil: $F_{1,76} = 19.1$, $P < 0.0001$); sucrose also was highly stimulatory ($F_{1,76} = 100.6$, $P < 0.0001$). The effects of winter savory and sucrose were additive, as shown by the non-significant interaction term (sucrose x plant oil: $F_{1,76} = 0.6$, $P = 0.44$) and the parallel lines in the interaction graph (Fig. 5A).

Two plant oils (tea tree and lemon) exhibited synergistic effects with sucrose, as shown by a significant interaction term (sucrose x plant oil: tea tree – $F_{1,76} = 8.0$, $P = 0.006$; lemon – $F_{1,76} = 5.1$, $P = 0.026$) and the nonparallel lines in the interaction graphs (Fig. 5B and C). For both plant oils, addition of the plant compound to sucrose (-) disks did not cause an increase in biting rates (comparison of simple-effects means, plant oil (+) versus plant oil (-) at sucrose (-): tea tree – $t_76 = 0.8$, $P = 0.44$; lemon – $t_76 = 1.9$, $P = 0.06$). Conversely, addition of the plant oil to sucrose-treated disks did elicit higher rates of biting (plant oil (+) versus plant oil (-) at sucrose (+): tea tree – $t_76 = 4.8$, $P < 0.0001$; lemon – $t_76 = 5.1$, $P < 0.0001$).

Both cedarwood and garlic appeared to inhibit response of wireworms to presence of sucrose (Fig. 5D and E). The plant oil x sucrose interaction was significant for both products (cedarwood: $F_{1,76} = 4.6$, $P = 0.035$; garlic: $F_{1,76} = 5.3$, $P = 0.025$). Addition of either plant oil to sucrose (-) disks failed to cause significant changes in biting response

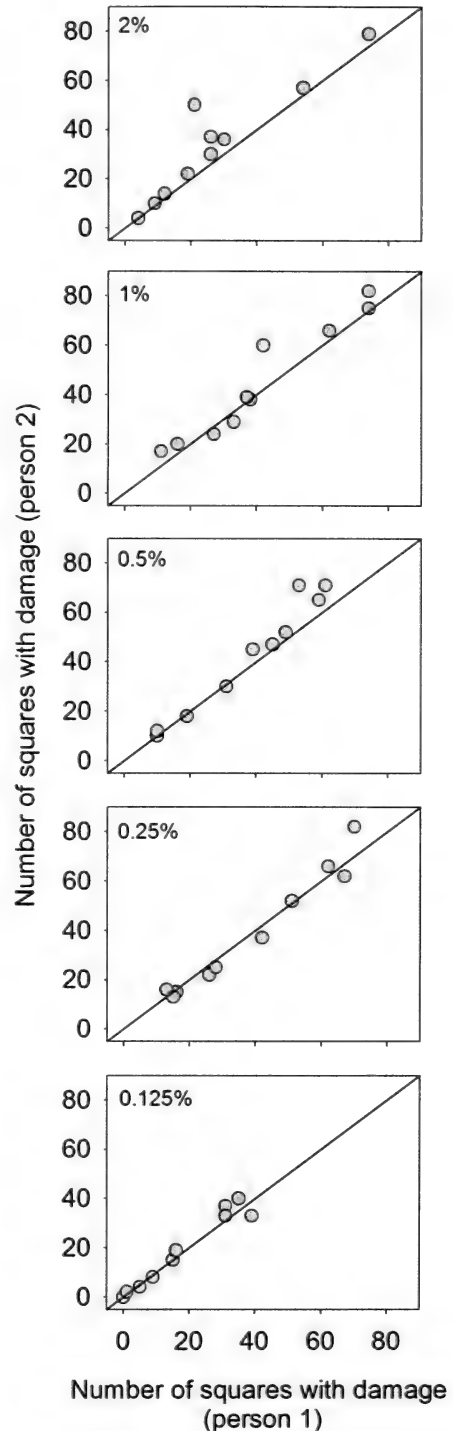


Figure 2. Scatter plots showing results for first (person 1) and second (person 2) estimates of damage; sucrose-treated disks ($N = 10$ disks per concentration). Correlations varied between 0.930 (2% concentration) and 0.982 (0.5% concentration).

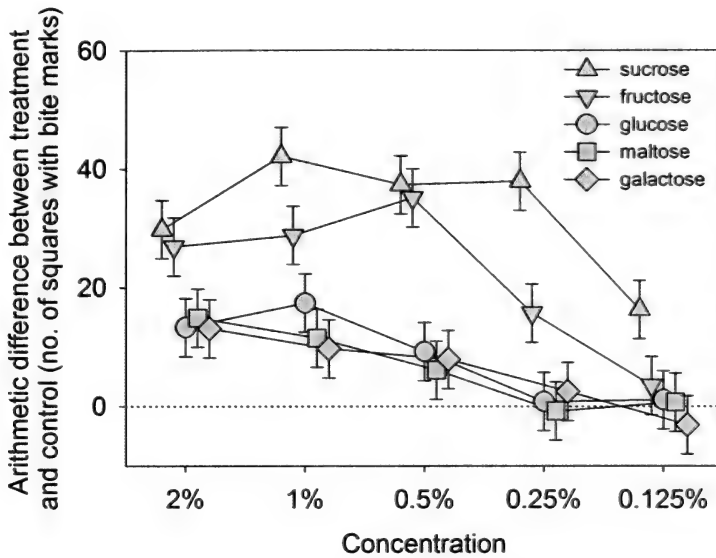


Figure 3. Mean (+ SEM) arithmetic difference between treatment (sugar) and control disks in number of squares showing feeding damage. Means are shown as a function of sugar concentration. Each mean is based upon 10 replicates.

(cedarwood: $t_6 = 0.8$, $P = 0.43$; garlic: $t_6 = 0.7$, $P = 0.52$). In contrast, adding either plant oil to the sucrose (+) disks actually led to statistically significant drops in biting rates

compared to rates seen on the sucrose (+) treatment (cedarwood: $t_6 = 2.2$, $P = 0.029$; garlic: $t_6 = 2.6$, $P = 0.011$).

DISCUSSION

The plant-associated cues that mediate feeding by wireworms or other subterranean insects are often inadequately known, in large part due to difficulties in studying these insects (Johnson and Gregory 2006; Johnson and Nielson 2012). This shortcoming may be especially pronounced for generalist species such as *L. canus*, given that its generalized feeding habits provide no obvious clues as to what plant compounds might elicit feeding. Several different approaches have been used to screen compounds as potential feeding stimulants or deterrents for either generalist or specialist root-feeders, most of which comprise an analysis of feeding or biting activity by the insect on a substrate that has been treated with the compound of interest. Substrates used in these assays have been quite diverse, and include at a minimum products such as filter paper disks (Thorpe *et al.* 1947; Wensler and Dudzinski 1972; Bernklau and Bjostad 2005), cellulose membrane disks (Ladd 1988; Allsopp 1992), thin sections of potato tuber (Villani and

Gould 1985), pith wafers (Thomas and White 1971), or agar (Tanton 1965). The assay developed here provided a repeatable means for estimating biting response of *L. canus* on treated filter paper disks.

Cues that prompt feeding by root-feeding Coleoptera often include any of several sugars (Chrysomelidae: Bernklau and Bjostad 2008; Scarabaeidae: Wensler and Dudzinski 1972, Ladd 1988, Allsopp 1992; and Elateridae: Thorpe *et al.* 1947, Crombie and Darrah 1947). Indeed, in a review of subterranean insects and their interactions with host plants, Johnson and Gregory (2006) showed that 48% of the chemical compounds shown to stimulate feeding by root-feeding insects were sugars. Thorpe *et al.* (1947) showed that the wireworms *Agriotes lineatus*, *A. sputator*, and *A. obscurus* were stimulated to bite filter paper disks if those disks had been treated with a sugar. Varietal differences in susceptibility of potato tubers to wireworm feeding are affected in part by levels of sugars in the tubers (Olsson and Jonasson 1995).

Here, we showed that biting of filter paper disks by *L. canus* was induced by any of five sugars, with sucrose and fructose being the most stimulatory (Fig. 3). Intensity of feeding, as estimated by counting bite marks, showed a decline with decreasing concentration of sugar in the solutions, to the extent that highly dilute concentrations of most products were not stimulatory (Fig. 3).

Plant compounds may interact either positively or negatively to affect feeding rates of phytophagous insects (Hsiao and Fraenkel 1968; Shanks and Doss 1987). Sugars have been shown to act synergistically with other (non-sugar) compounds in eliciting feeding behavior by above-ground and below-ground phytophagous insects (Crombie and Darrah 1947; Shanks and Doss 1987; Bartlet *et al.* 1994). Our assays with plant essential oils in combination with sucrose demonstrated any of three effects, depending upon the plant oil: additive, synergistic, and antagonistic. The exact mechanisms leading to these results are not clear, but could have included both gustation and olfaction. Volatiles from plant

essential oils are known to affect both short- and long-distance attraction and aversion responses of phytophagous insects (Landolt *et al.* 1999; Robacker 2007; Youssef *et al.* 2009). Similarly, gustatory signals from plant essential oils may inhibit or elicit feeding response (Tanton 1965; Klepzig and Schlyter 1999). Thus, the additive or synergistic effects observed here between sucrose and tea tree or sucrose and lemon theoretically could have been the result of either of two processes: (1) the plant essential oil acted as an additional feeding stimulant; or, (2) the plant oil acted as an olfactory cue that attracted the wireworm to the treated disk, and biting was then elicited by the sucrose. Antagonistic effects (Fig. 5DE) could have been due to inhibition of sugar receptors by the second compound (Ishikawa *et al.* 1969) or because the plant essential oil was modestly repellent (e.g., van Herk *et al.* 2010) and slowed how rapidly wireworms approached the sucrose-treated disks.

Historical efforts to use insecticide-laced baits for controlling wireworms have often

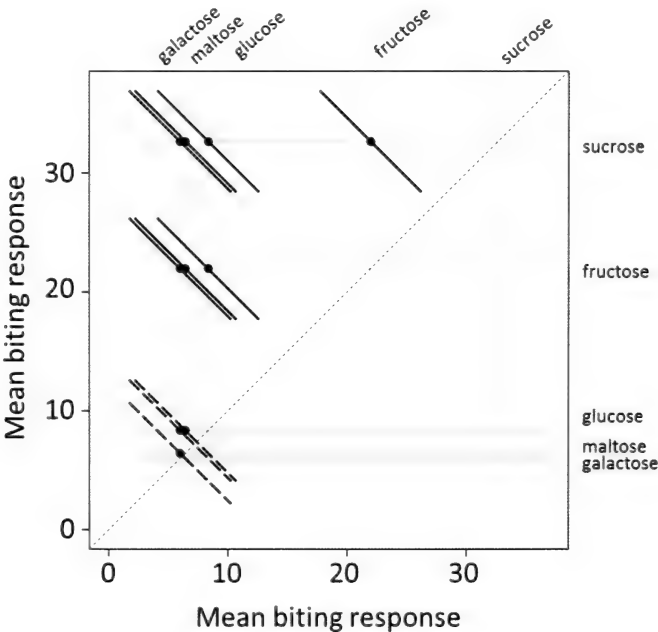


Figure 4. Diffogram showing results of Tukey-Kramer test for separating sugar means. Diagonal, upward sloping line depicts equality. Each solid circle shows joint location of two sugar means; the associated solid or dashed lines show confidence intervals for treatment differences (Tukey-adjusted). A confidence interval that intersects the equality line indicates that those two means are not statistically different (shown as dashed lines); a confidence interval that fails to intersect the equality line indicates that those two means are statistically different (shown as solid lines).

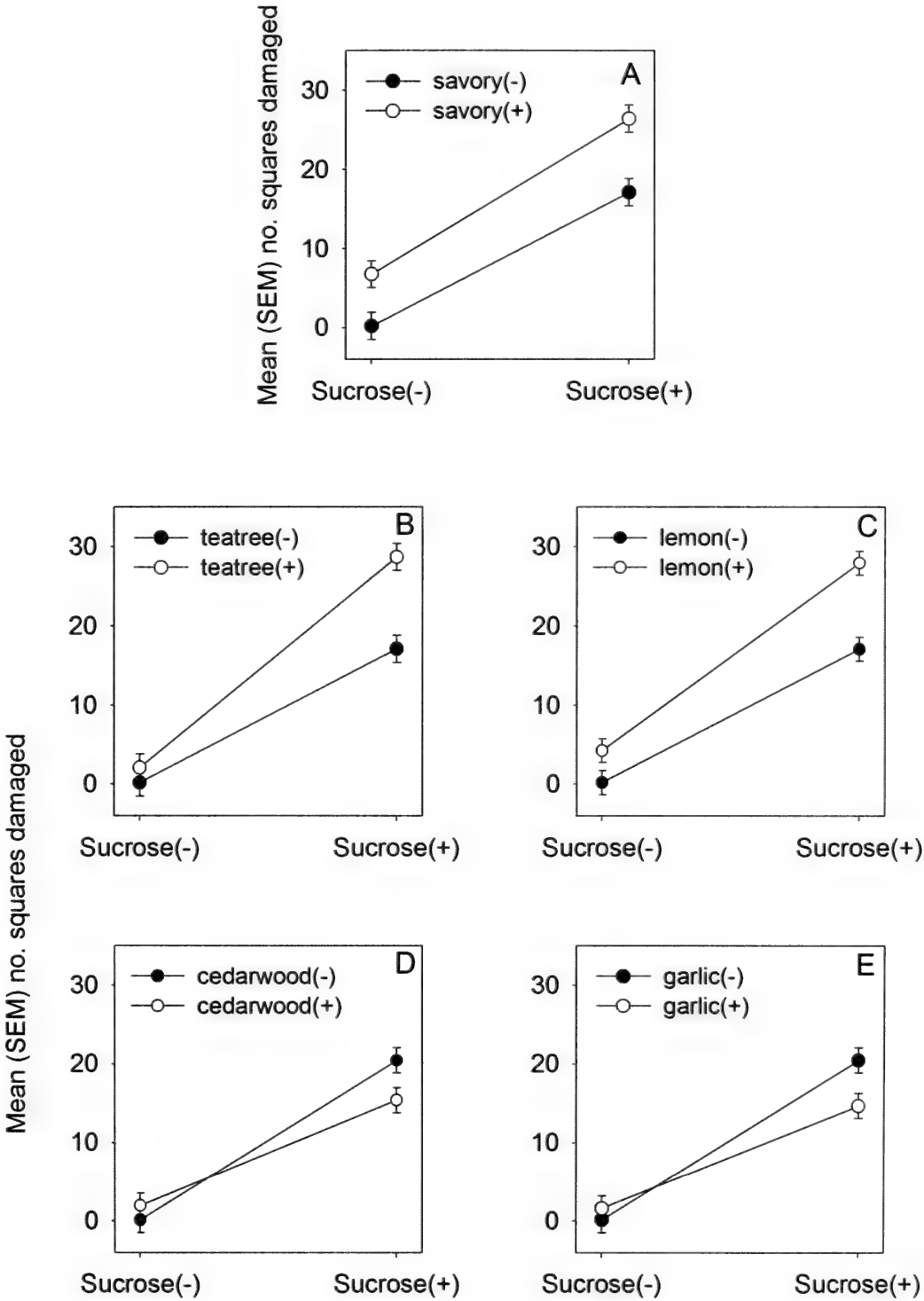


Figure 5. Interaction graphs showing the separate and combined effects of sucrose and plant essential oils on damage to filter paper disks. A: an additive effect; B and C: synergistic effects; D and E: antagonistic effects. Each mean based upon 20 replicates.

been unsuccessful (Lehman 1933; Woodworth 1938), apparently due to antifeedant or repellent effects of the toxicant (see also Long and Lilly 1958; van Herk and Vernon 2007). Addition of an appropriate phagostimulant could theoretically lead to improved rates of kill. For example, in trials with western corn rootworm larvae, *Diabrotica virgifera* LeConte (Coleoptera: Chrysomelidae), addition of a phagostimulant to insecticide-treated disks of filter paper led to higher rates of feeding on disks and increased kill of larvae than found in the absence of the

phagostimulant (Bernklau and Bjostad 2005; Bernklau *et al.* 2011). The studies summarized here provide a simple tool for screening of compounds for gustatory effects, including non-additive effects elicited by combinations of products, with possible longer-term benefits of developing a palatable bait. Additional compounds such as proteins or fatty acids shown in filter paper assays to elicit biting responses of other wireworm species (Thorpe *et al.* 1947) also merit attention for effects on *Limoni* spp. wireworms.

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Success of *Grapholita molesta* (Busck) reared on the diet used for *Cydia pomonella* L. (Lepidoptera: Tortricidae) sterile insect release

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ABSTRACT

The survival and development of *Grapholita molesta* (Busck) reared from egg to adult on the synthetic diet currently used by the Okanagan–Kootenay Sterile Insect Release Program to mass rear *Cydia pomonella* L., in Osoyoos, British Columbia, was compared to those of *G. molesta* reared on the synthetic diet normally used to rear *G. molesta* in the laboratory. Survival and development on a diet of crab apples were tracked as a control. The fitness of resulting moths was compared using metrics of survival to pupation and pupal weight, survival to adulthood, and female fecundity. More *G. molesta* reached the pupal stage and had significantly greater mass when reared on the *G. molesta* diet than on either the *C. pomonella* diet or the crab apple diet. Numbers of moths surviving to adulthood were similar for all three diet types. Although larval diet affected pupal mass of *G. molesta*, the resulting females produced a statistically similar number of offspring, regardless of diet. This study suggests that *Grapholita molesta* can be reared successfully on the diet currently used to rear *C. pomonella* for sterile insect release, but mass production of *G. molesta* will require modification, as well as a period of adaptation to this novel food source.

Key Words: Oriental fruit moth, *Grapholita molesta*, Codling moth, *Cydia pomonella*, Sterile Insect Release

INTRODUCTION

The Oriental fruit moth (OFM), *Grapholita molesta* (Busck) (Lepidoptera: Tortricidae), is an economically destructive pest of stone and pome fruits, including peaches and apples (Rothschild and Vickers 1991), and is considered a key pest in many fruit-growing regions (Rothschild and Vickers 1991, Bellutti 2011). Female OFM lay eggs on or adjacent to young shoots and fruits. Upon hatching, neonate larvae usually penetrate the host within 24 h (Dustan 1960). Early in the season, they feed on new growth of twig terminals; after twigs mature, larvae feed internally on the host's fruit (Rothschild and Vickers 1991, Notter-Hausman and Dorn 2010).

The OFM originated in Central Asia (Roehrich 1961) and has spread to most of the world's temperate fruit-growing regions. It was first brought to North America on

ornamental fruit trees in the early 1900s, and now occurs in most stone-fruit growing regions of Canada and the USA (Rothschild and Vickers 1991). British Columbia (BC) remains the only temperate fruit-growing region in the world free of this pest and, as such, its orchard industry is at constant risk of inadvertent introduction of this internally feeding insect.

An absence of OFM and other pests of apples in BC justified attempts to eradicate the only key pest, codling moth (CM), *Cydia pomonella* (L.) (Lepidoptera: Tortricidae), from the province's montane fruit-growing valleys (Dyck *et al.* 1993). In 1992, the Okanagan–Kootenay Sterile Insect Release Program was launched to eradicate CM from southern BC's Okanagan and Similkameen valleys (Dyck *et al.* 1993). Although eradication has not yet been achieved, a

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combination of sterile insect release (SIR) and other integrated pest management (IPM) tactics (Judd and Gardiner 2005) has provided area-wide suppression of this key pest of pome-fruit production in BC (Bloem *et al.* 2007).

Success of SIR against CM may eventually lead to the underutilization of the program's rearing facility in Osoyoos, BC, and additional uses for the facility are being considered. Possible alternative uses include the rearing of biological control agents that could supplement IPM programs for other BC crops or the rearing of other pest insects that might be controlled by SIR programs.

If OFM is introduced to BC, the insect may be a potential target for control by SIR technique. Preliminary trials in Bulgaria have shown that population densities of OFM on peaches were reduced during a pilot program that combined classic SIR with F₁ male sterility (Genchev 2002).

Development and reproductive output in OFM are significantly affected by the nutritional quality of their host plant (Meyers 2005, Meyers *et al.* 2006a). Low-quality larval food negatively affects OFM body size and flight capacity (Gu and Danthanaraya 1992), and larger OFM are more fecund (Hughes *et al.* 2004).

The first step in developing the SIR technique to control any insect pest species is the development of a diet and mass-rearing system that are inexpensive and produce good-quality insects. An objective of this study is to assess the success, as defined by survival, development time and fecundity, of OFM when reared on the diet currently used to mass rear CM for SIR in the BC Interior. The study is designed to also provide preliminary information on whether rearing OFM in the SIR facility currently used to mass rear CM is possible and feasible.

MATERIALS AND METHODS

Insects. The OFM eggs used in this experiment were obtained from a colony reared under laboratory conditions (16:8 h light:dark, 24° C) for ~ 8 y (~12 generations per year) on a lima bean-based diet (Shorey and Hale 1965). The colony was originally obtained from Dr. Mitch Trimble at Agriculture and Agri-food Canada, in Vineland, Ontario. The eggs were collected from a 15 × 15 cm wax-paper roll that served as an oviposition substrate within a wooden mating chamber (31 × 18.5 × 18.5 cm). Viable eggs were determined by egg colour and were counted using a dissecting microscope. Groupings of 10–25 eggs were cut away from the wax paper. Sterile pins were used to arrange a total of 200 eggs on each diet, so that newly hatched neonate larvae could balloon directly onto the diet treatment (as described below). Three replicates of each diet type—codling moth diet (CMD), Oriental fruit moth diet (OFMD), and crab apple diet (ApD)—were conducted, for a total of 600 eggs per treatment.

Codling Moth Diet. The codling moth diet (CMD) is a sawdust-based larval diet modified from a diet originally developed by Brinton *et al.* (1969). The CMD currently contains a sawdust mixture obtained from

mills processing Douglas-fir and larch logs (Scott Arthur, Facilities Engineer, Sterile Insect Rearing Facility, Osoyoos, BC, personal communication). The CMD was obtained from the Okanagan–Kootenay Sterile Insect Release Program, in Osoyoos, BC. The ingredients (per kilogram of diet) were as follows: 717.00 ml distilled water; 12.40 g paper/wood pulp; 26.90 g casein; 9.00 g wheat germ; 18.00 g wheat bran; 26.90 g sucrose; 98.60 g whole wheat flour; 11.00 g ascorbic acid; 6.10 g vitamin mixture; 6.20 g Wesson's salt mixture (Cohen 2004); 4.94 g Aureomycin®; 2.70 g sorbic acid; 68.90 g sawdust; and, 9.00 g citric acid. The vitamin mixture was as follows, in grams per kilogram: 5.00 niacinamide, 5.00 calcium pantothenate, 1.30 thiamin hydrochloride, 1.30 folic acid, 0.10 biotin, 1.01 Vit. B12, 1,804.00 ascorbic acid, 449.00 sorbic acid. Five-hundred millilitres (500 ml) of CMD were poured into a plastic rearing box (21 × 22 × 7 cm) and allowed to reach room temperature for 60 min prior to experimental use.

Oriental Fruit Moth Diet. The OFM diet (OFMD) is the same lima bean-based diet adopted from Shorey and Hale (1965), and used to maintain the laboratory colony

described above. The ingredients include, per 1.30 litres: 400.00 g organic lima beans, *Phaseolus lunatus*; 80.00 g brewer's yeast; 8.00 g ascorbic acid (coated with fibre); 5.00 g methylparaben (USP); 2.00 g sorbic acid (FCC); 25.00 g vitamin mix (Vandersant-Adkisson); 18.00 g carrageenan (Irish moss); and, 2,500.00 ml distilled water. The lima beans were purchased from Planet Organic, Edmonton, Alberta; all other ingredients were purchased from Bio-Serv®, New Jersey, USA. Five-hundred millilitres (500 ml) of OFMD were poured into a plastic rearing box (21 × 22 × 7 cm) and allowed to dry for 60 min.

Apples. The apples (ApD) used as a control diet were 'Dolgo' crab apples (*Malus* spp.) collected in Edmonton, Alberta, in late August, 2011. The apples were rinsed first with 1.5% bleach solution, then with distilled water. The apples were left to dry for 10 min on paper towel before being placed into plastic rearing boxes (21 × 22 × 7 cm) to ≈ 500 ml volume.

After being placed into rearing containers, all three diets were sterilized with ultraviolet radiation for 30 s (Kowalski 2009).

Experimental Procedure. Each rearing box contained 200 OFM eggs that were evenly distributed across the diet surface. The boxes were sealed with screened lids and held in a growth chamber at 24 °C, for 16:8 (light:dark) h. Initial hatch success of eggs positioned on diet was determined by number of unhatched and hatched eggs. Larvae were allowed to develop until the wandering stage, at which point two 5 × 12 cm cardboard strips were placed into each rearing box to provide pupation sites.

Every 2–3 days, fine forceps were used to remove pupae from their cocoons. The pupae were weighed on a microbalance (Mettler Toledo XS105) to the nearest 0.01 mg, and

each was placed into its own 30-ml plastic cup until adult eclosion.

Adult moths were separated by sex, and the first 10 male and female moths per replicate from each diet were established as mating pairs ($N = 30$ pairs per diet treatment). Each moth pair was placed in its own 30-ml plastic cup that was lined with wax paper as an oviposition substrate. Plastic mesh was glued to the inside of the lid of each cup to deter oviposition on the lid. Moths were provided with a 10% sucrose solution via a dental wick inserted through the cup lid. Mating pairs were maintained under the same conditions as those provided for larval rearing. Upon mortality of the females in each mating pair, the number of hatched and unhatched eggs laid per female was counted.

Statistical Analyses. Response variables were visually assessed for assumptions of normality. Initial hatch success was determined by number of hatched and unhatched eggs found on the egg sheets, and a mixed-effects model, with replicate serving as the random variable, was used to determine differences in initial hatch success among the diets. A mixed-effects model was used to determine effect of diet type and sex on pupal mass, with replicate designated as a random effect. Multiple comparisons were conducted using t-values from the summary output ($\alpha = 0.05$). A logistic regression model was used to analyze effect of diet and pupal mass on survival to adulthood. Replicate was included as a blocking factor in the logistic regression model. We used a mixed-effects model, with replicate as the random effect, to determine relationship between female pupal mass and diet on fecundity (total eggs laid), and a square-root transformation to normalize data. Statistics were conducted using R (R Core Team 2012). Differences were deemed significant at $P < 0.05$.

RESULTS

Initial hatch success. The emergence of OFM neonate larvae from eggs did not differ by diet type ($F = 2.69$; $df = 2$; $P = 0.182$; Table 1).

Pupation. Numerically, but not statistically, more larvae developed to pupae on the OFMD than on either the CMD or ApD (Table 1). The interaction between diet and

sex ($F = 6.22$; $df = 2$; $P = 0.0022$), and the main effects of diet ($F = 116.82$; $df = 2$; $P < 0.0001$) and sex ($F = 126.81$; $df = 1$; $P < 0.0001$), had significant effects on pupal mass (Fig. 1). Larvae reared on the OFMD and the CMD emerged from the diet in search of a pupation site within the same 24-h period. Pre-pupal wandering in the ApD occurred >

Table 1

Mean (\pm SE) numbers of Oriental fruit moth surviving to various life stages on different diets.

Diet	Initial hatch success ^a	Pupae	Adults
Codling moth	188.67 \pm 6.39	48.33 \pm 4.74	34.00 \pm 4.19
Oriental fruit moth	186.00 \pm 4.36	67.33 \pm 2.84	48.33 \pm 2.88
Apples	181.67 \pm 9.33	48.67 \pm 5.10	30.33 \pm 5.81

^aIncludes three replicates of 200 eggs reared on each diet.

48 h later than it had on either the CMD or the OFMD.

Survival to adulthood. The proportion of individuals that survived to adulthood was low on each diet treatment (Table 1). Survival to adulthood was not dependant on pupal mass ($df = 1$; $P = 0.79$), diet type ($df = 2$; $P = 0.91$), nor the interaction between pupal mass and diet ($df = 2$; $P = 0.91$).

Female fecundity. Females reared on OFMD produced the most offspring numerically (Table 2). However, diet treatment ($df = 2$; $F = 0.40$; $P = 0.67$), female pupal mass ($df = 1$; $F = 1.18$; $P = 0.28$), and the interaction between diet and pupal mass did not significantly influence female fecundity ($df = 2$; $F = 0.80$; $P = 0.45$).

DISCUSSION

Our results indicate that the CMD can be used to rear OFM, but the condition of moths reared on the CMD was poorer than that of the moths reared on the OFMD. The initial hatch of OFM eggs on each diet was high and did not differ by diet type. Diet type influenced the mass of pupae, which may reflect

differences in the nutritional quality of the diets. The larvae reared on the OFMD were the largest, followed by larvae reared on the ApD, with the CMD producing the lowest pupal weights. Yokoyama *et al.* (1987) found that OFM reared as larvae on apples were significantly smaller in mean pupal mass than

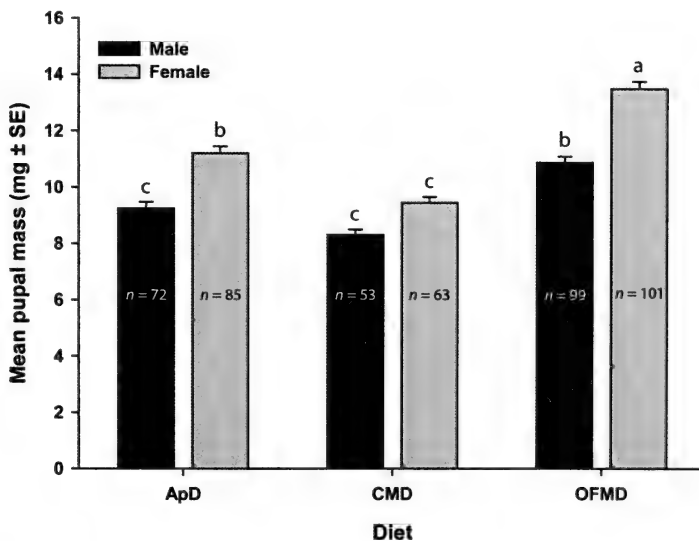


Figure 1. Mass of male and female Oriental fruit moth pupae on the codling moth diet (CMD), the Oriental fruit moth diet (OFMD), and crab apples (ApD). Bars marked with different letters are significantly different ($\alpha = 0.05$).

Table 2

Mean (\pm SE) fecundity of female Oriental fruit moth in each of three replicates when reared on different diets.

Diet ^a	Replicate	Female fecundity ^b	No. of mating pairs (<i>n</i>)
Codling moth	I	73.33 \pm 7.68	8
	II	52.13 \pm 5.59	10
	III	38.00 \pm 6.16	10
Oriental fruit moth	I	90.5 \pm 8.90	10
	II	78.5 \pm 8.78	10
	III	39.2 \pm 6.52	10
Apples	I	88.25 \pm 8.51	8
	II	62.40 \pm 8.02	7
	III	41.20 \pm 5.76	9

^aPairs of virgin males and females reared from each diet type.

^bMean eggs laid per female. Female fecundity defined as total eggs laid.

those resulting from larvae reared on the lima bean diet. High survival occurs when OFM are reared on fresh thinning apples, but both survival and pupal mass decline as apple quality degrades over time (Vetter *et al.* 1989). Our experiment showed a decline in female fecundity among all three diet types in the latter replicates, particularly in replicate III. In our experiment, each diet resulted in 20–40% survival, which is comparable to larval survival on apple and peach twigs and fruit under field conditions in the eastern USA (Myers *et al.* 2006b), but is lower than that on other synthetic diets (Genchev 2002). More larvae reached pupation when reared on the OFMD than on the CMD or ApD. This may indicate that the insects used in this study were adapted to the diet the laboratory colony had been reared on for many preceding generations. In the Bulgaria study, emergence of adult female OFM was consistent, but fecundity increased with number of generations reared on two synthetic diets (Genchev 2002). Further research should determine if OFM survival increases on the CMD after multiple consecutive generations are reared on this new food source.

Both male and female pupae reared as larvae on the OFMD were significantly larger than pupae of larvae reared on the CMD or the ApD. Oriental fruit moth larvae deprived of food have an increased rate of pre-imaginal

development, with smaller pupae resulting (Hughes *et al.* 2004). Laboratory flight bioassays indicate OFM adults that eclose from small pupae do not fly as far as those that eclose from large pupae (Hughes *et al.* 2004). The suboptimal pupal weights attained by OFM reared on the CMD in the current study may reduce the flight capacity of the resulting moths.

Larval development time varied among the diets tested. The pre-pupal wandering stage on the ApD occurred 48 h later than on either synthetic diet tested. This may be due to differences in penetration of light into the natural versus the synthetic diet types, which can affect behaviour of last-instar larvae (Nylén *et al.* 2008). Apple skin contains phenolics that protect the fruit from UV damage (Solovchenko and Schmitz-Eiberger 2003). This may have decreased the amount of penetration of light radiation into the ApD, as compared to the CMD or OFMD. Short photophase duration correlates with increased pre-imaginal mortality and delayed reproduction in OFM (Hughes *et al.* 2004).

Larval development of OFM is faster on peach than on any other host, including apple (Bellutti 2011). Oriental fruit moth females prefer peach trees over apple trees for oviposition in close-range controlled tests (Meyers 2005). This preference may involve nutritional components found in peach that are

not present in apple. The crab apples used in the current study were reaching full maturity at the time of picking. Sugar levels and the allelochemistry of apples can vary as the fruit matures (Meyers *et al.* 2006b); this variation may change the fruit's suitability for larval development. For instance, larval CM survival is optimal as pear fruit approach maturity, but decreases as the fruit loses firmness with ripening (Van Steenwyk *et al.* 2004). Decreased penetration of the crab apple skin might also slow development and explain the 48-h delay in the pre-pupal wandering on the ApD.

Although diet type significantly influenced pupal mass in this study, females were similarly fecund, regardless of diet type. Body size is a good indicator of fitness in many moths (Tammaru *et al.* 2002), including OFM (Hughes *et al.* 2004). Compounds obtained from fruit by OFM larvae are used in the synthesis of courtship pheromones by male moths (Baker *et al.* 1981). Males reared on formulated synthetic diets lack trans-ethyl cinnamate, a compound sequestered from apples and peaches (Baker *et al.* 1981) that dictates mate acceptance by females (Loftstedt *et al.* 1989). Other diets used to rear OFM for SIR in Bulgaria incorporate peach and apple purée into the synthetic diet (Genchev 2002). The incorporation of trans-ethyl cinnamate or fruit purées into synthetic diets for OFM should be examined before mass rearing is considered.

The Okanagan–Kootenay Sterile Insect Release Program, in combination with other tactics (Judd and Gardiner 2005), has provided area-wide suppression of CM populations in

BC's Okanagan and Similkameen valleys (Bloem *et al.* 2007). This multi-million-dollar facility may soon be underutilized, but could be used to rear other insects for SIR. Adaptation of the facility to house another closely related species would be most cost effective if minimal changes to the rearing techniques currently used for CM were required.

Wood-based diets such as the CMD are more effective for mass insect rearing, because they are less susceptible to mould growth than agar-based diets are, and wood is a less costly binding material than agar (Brinton *et al.* 1969). The first step in developing the SIR technique for any species is the development of an inexpensive mass-rearing system, including diet. Although the agar-based diet used to rear OFM in this study produced good-quality moths, the diet would be too expensive for large-scale mass production of moths in the SIR facility. Our results show that OFM can be reared on the diet currently used for CM SIR. The quality of mass-reared insects is critical to the success of a SIR program (Calkins and Ashley 1989). Therefore, further research into specific nutritional requirements for OFM should be investigated to determine if the CM diet can be modified to improve reared-insect quality. Our study's findings indicate that, based on pupal size as a measure of insect condition, the CMD is inferior to the OFMD, but that both diets produced equally fecund female moths. Further research would determine if OFM can readily adapt to the CMD after several generations of rearing.

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Additional provincial and state records for Heteroptera (Hemiptera) in Canada and the United States

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ABSTRACT

New provincial and/or state records are given for 73 species of Heteroptera in Canada and the United States. *Lygaeospilus brevipilus* is reported new to the United States, and *Corythaica acuta* and *Sehirus cinctus cinctus* new to Canada. *Eremocoris melanotus* is synonymized with *E. semicinctus*.

Key Words: Records, Heteroptera, Canada, United States

INTRODUCTION

Over the past few years, a study of the Heteroptera in various museum collections has resulted in the detection of a number of new provincial and state records for Canada and the United States. These records are additional to those listed for Canada in Maw et al. (2000) and subsequent publications. For the United States, the distribution records are additional to those listed in Henry and Froeschner (1988) and subsequent publications.

The higher classification follows Maw et al. (2000), but the lygaeid subfamily Orsillinae is raised to family status following Sweet (2000). Species are listed in alphabetical order under each family, and the data are cited as recorded on the specimen labels.

Museum abbreviations are as follows:

AMNH – American Museum of Natural History, New York, NY (R. T. Schuh)

CAS – California Academy of Sciences, San Francisco, CA (P. H. Arnaud, Jr., N. D. Penny)

CNC – Canadian National Collection of Insects, Agriculture and Agri-Food Canada, Ottawa, ON (R. G. Footitt)

DBUC – Department of Biological Sciences, University of Calgary, Calgary, AB (J. E. Swann)

JBWM – J. B. Wallis and R. E. Roughly Entomological Collection, University of Manitoba, Winnipeg, MB (T. Galloway, R. E. Roughley)

LEM – Lyman Entomological Museum, Macdonald College, McGill University, Ste-Anne-de-Bellevue, QC (S. Boucher, T. A. Wheeler)

NBM – New Brunswick Museum, St. John, NB (D. F. McAlpine)

NSM – Nova Scotia Museum of Natural History, Halifax, NS (A. Hebda, B. Wright)

OSU – Oregon State University, Corvallis, OR (J. D. Lattin)

PFC – Pacific Forestry Centre, Natural Resources Canada, Victoria, BC (L. M. Humble)

RAM – Royal Alberta Museum, Edmonton, AB (A. T. Finnermore)

RBCM – Royal British Columbia Museum, Victoria, BC (C. Copley, R. A. Cannings)

ROM – Royal Ontario Museum, Toronto, ON (D. C. Curry)

RSM – Royal Saskatchewan Museum, Saskatoon, SK (R. R. Hooper, R. Poulin)

UASM – Strickland Museum, Department of Biological Sciences, University of Alberta, Edmonton, AB (D. Shpeley)

UBC – Spencer Entomological Collection, Beaty Biodiversity Museum, University of British Columbia, Vancouver, BC (K. M. Needham)

UCB – Essig Museum of Entomology, University of California, Berkeley, CA (C. B. Barr)

USNM – United States National Museum, Washington, DC (T. J. Henry)

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WFBM – William F. Barr Entomological Museum, University of Idaho, Moscow, ID (W. F. Barr, F. W. Merichel)

WSU – James Entomological Collection, Department of Entomology, Washington State University, Pullman, WA (R. S. Zack)

NEW CANADIAN AND U.S. STATE RECORDS

Infraorder NEPOMORPHA

Family GELASTOCORIDAE

Gelastocoris oculatus (Fabricius)

The Gelastocoridae were revised by Todd (1955), who provided a key to species. *Gelastocoris oculatus* is widely distributed in the United States, but in Canada, it is reported from only British Columbia, Manitoba, and Ontario (Maw et al. 2000).

New record. **VIRGINIA**: 3♂ 1♀, Botetourt Co., Buchanan, James R., 27.vi.1993 (H. Nadel) [RBCM].

Infraorder LEPTOPODOMORPHA

Family SALDIDAE

Saldula nigrita Parshley

The Canadian species of *Saldula* have been keyed by Brooks and Kelton (1967). *Saldula nigrita* is widely distributed across Canada, and it has been recorded from the Yukon (Scudder 1997).

New record. **NORTH WEST TERRITORIES**: 2♂, Martin R., 61°55'N 121°35'W, MR3-3S120772, Pan trap 2, 12.vii.1972 (MacKenzie Valley Pipeline Study Fort Simpson Region) [CNC].

Infraorder CIMICOMORPHA

Family NABIDAE

Pagasa fusca (Stein)

Kerzhner (1993) distinguished *Pagasa fusca* from *P. nigripes* Harris on the basis of differences in the male and female genitalia. He noted that, in *Pagasa fusca*, the legs are yellow and the femora orange or reddish. Kerzhner (1993) clarified some of the earlier distribution records for *P. fusca*, but did not cite the species from Washington State.

New record. **WASHINGTON**: 1♂, Walla Walla, ix.1931 (K. E. Gibson) [WFBM].

Family MIRIDAE

Deraeocoris incertus Knight

This species can be identified by using the keys in Knight (1921) and Razafimahatrata (1981). It has previously been recorded in Canada from only British Columbia (Maw et al. 2000).

New record. **ALBERTA**: 1♀, Kananaskis, Barrier Lake Field Station, 51°01'49"N 115°02'W, Malaise trap, 900-2100, 8.viii.2009 (Larry Wu) [DBUC].

Melanotrichus coagulatus (Uhler)

Illustrated by Kelton (1980) and keyed by Kelton (1980) and Henry (1991), *M. coagulatus* has silvery scale-like setae on the dorsum in patches, a membrane with a small dusky-brown patch just beyond the veins, and brown to fuscous tibial spines. The insect is widely distributed in North America (Henry and Wheeler 1988; Maw et al. 2000) and was previously recorded from the Yukon (Scudder 1997).

New record. **ALASKA**: 2♂ 2♀, Fairbanks, U. of A. Campus, Malaise trap powerline cut, 26.vi-1.vii.1979 (B. Wright) [NSM].

Paraproba cincta Van Duzee

Schwartz and Scudder (2000) clarified the identity of *Paraproba cincta* and made *P. nigrivervis* Van Duzee a junior synonym. *Paraproba cincta* can be distinguished from *P. hamata* Van Duzee by the following characteristics: in *P. cincta*, the length of the lateral margin of the cuneus is equal to or greater than the posterior width of the pronotum, the apex of the clavus lacks a small black mark, and the corium is uniformly pale green and has no faint black cloud.

New record. **ALBERTA**: 1♂, Kananaskis, University of Calgary Barrier Lake Field Station, 51°01'49"N 115°02'W, Malaise, meadow site, viii.2003 (AMNH_PBI 00395256) [DBUC].

Pinalitus solivagus (Van Duzee)

The species of *Pinalitus* in North America were keyed by Kelton (1977). *Pinalitus solivagus* can be distinguished by the mottled hemelytra, short rostrum, and shape of the male parameres.

New record. **ALBERTA**: 1♀, Kananaskis Field Station, 51°01'49"N 115°02'W, gravel pit site, 6-11.viii.2003 (AMNH_PBI 00395238) [DBUC].

Plagiognathus albatrus (Van Duzee)

Plagiognathus albatrus was keyed recently by Schuh (2001), who also provided a colour photograph of the species. Schuh (2001) cites the distribution as eastern North America, from Quebec south to the Gulf Coast, west to central Texas and the foothills of the Colorado Rockies. In Canada, *P. albatrus* is recorded from most provinces east of Alberta (Schuh 2001). The following record for British Columbia evidently represents an alien introduction.

New record. **BRITISH COLUMBIA**: 5♂, 2♀, Kelowna, ex *Platanus hybrida* Brot., vi. 2012 (S. Archeampong) [CNC].

Plagiognathus shoshonea Knight

Plagiognathus shoshonea was keyed recently by Schuh (2001), who also provided a colour photograph of the species. In Canada, *P. shoshonea* has been reported previously from Alberta and British Columbia (Maw et al. 2000).

New record. **SASKATCHEWAN**: 1♀, Fort Walsh, prairie hillside, 2.viii.1979 (K. Roney) [RSM].

Prepops borealis Knight

This species was keyed by Kelton (1980). It is distinguished by the black scutellum and black hemelytra. In Canada, *P. borealis* had been reported previously from British Columbia to Nova Scotia (Maw et al. 2000).

New record. **NORTH WEST TERRITORIES**: 2♂, Martin R., 61°55'N 121° 35'W, MR3-3S200772, Pan trap 4, 20.vii. 1972 (MacKenzie Valley Pipeline Study Fort Simpson Region) [CNC].

Sericophanes heidemanni Poppius

Keyed and illustrated by Kelton (1980), this species was previously reported in Canada, from British Columbia to Saskatchewan, and also in Ontario and Quebec (Maw et al. 2000).

New record. **NOVA SCOTIA**: 1 (abdomen missing), Lun. Co., New Ross, swept from marsh at Ross Farm, 31.vii.1984 (Wright, Morris) [NSM].

Sixeonotus rostratus Knight

Keyed and illustrated by Kelton (1980), this species has previously been recorded in

Canada from only Alberta and Saskatchewan (Maw et al. 2000).

New record. **BRITISH COLUMBIA**: 1♂, Bull River Valley, south end, 49°29'41.3"N 115°24'51.2"W, 11U 614832 5483663, 873m, 28.vii.2011 (C. & D. Copley) [RBCM].

Trigonotylus flavicornis Kelton

Recently keyed with characteristics illustrated by Scudder and Schwartz (2012), this species has been recorded in North America from only Manitoba and Saskatchewan (Kelton 1970, 1980; Henry and Wheeler 1988; Maw et al. 2000).

New records. **BRITISH COLUMBIA**: 2♂ 4♀, Chilcotin, 27.vii.1920 (E. R. Buckell) [CNC; UBC]; 1♂, Chilcotin, 20.viii.1930 (G. J. Spencer) [CNC].

Family TINGIDAE*Corythaica acuta* Drake

This species is keyed by Gibson (1919) and Hurd (1945). It has been recorded from only Colorado, Montana, and Nevada (Froeschner 1988f). G. G. E. Scudder collected comparative material in Colorado (Pawnee Nat. Grassland Hdq., 9.viii. 1973). This entry represents a new species for Canada.

New records. **ALBERTA**: 1♂, CFB Suffield, NWA, 50°23.466'N 110°36.768'W, PT 1.3.2, 1-16.vi.1994 (A. T. Finnamore) [RAM]; 3♀, id., PT 1.3.3, 16-29.vi.1994 (A.T. Finnamore) [CNC; RAM]; 1♀, id., PT 1.3.2, 16-29.vii.1994 (A. T. Finnamore) [RAM]; 3♀, id., PT 1.3.3, 16-29.vii.1994 (A. T. Finnamore) [CNC; RAM]; 1♂, id., PT 1.3.2, 16.viii-17.ix.1994 (A. T. Finnamore) [RAM].

Hesperotingis occidentalis Drake

This species is distinguished from other species in the genus in northwest North America by the following characteristics: a rostrum that reaches only the middle coxae, and a costal area of the corium that has one complete row of areoles in the middle and a double row of areoles near the base and the apex.

New record. **MONTANA**: 7♀, Glacier N.P., Babb, 10 mi W, 8.viii.1969 (Oman) [OSU].

Infraorder PENTATOMOMORPHA**Family ARADIDAE**

Aradus aequalis Say

Keyed by Matsuda (1977), with photographs of both male and female in dorsal view, this species has been recorded in Canada from only Ontario and Quebec (Matsuda 1977; Maw et al. 2000). However, it is widely distributed in the eastern United States (Froeschner 1988a).

New record. **MICHIGAN**: 4♀, Ingham Co., Michigan St. U. Campus, 12.viii.1978 (B. D. Ainscough) [RBCM].

Aradus kormilevi Heiss

This species was keyed and illustrated by Matsuda (1977) as *Aradus cinnamomeus* Panzer. However, Heiss (1980) showed that North American specimens under this name were a new species. *Aradus kormilevi* occurs across Canada from British Columbia to Nova Scotia (Maw et al. 2000), and is widely distributed in the United States (Froeschner 1988a).

New record. **OREGON**: 1♂ 2♀, Lake Co., 23 mi W of Adel, under bark, 17.v.1957 (W. J. Hogg) [RBCM].

Aradus nigrinus canadensis Parshley

Described by Parshley (1929) from Banff, Alberta, and keyed by Matsuda (1977), this aradid has to date been recorded from only Alberta.

New record. **BRITISH COLUMBIA**: 1♂, Monkman Rd. [mi 15], *Picea glauca*, 15.vi.1965 [(R. Wood)] (FIS 65-5793-01) [PFC].

Aradus similis Say

Keyed and illustrated by Matsuda (1977), this species has not previously been recorded from New Brunswick (Maw et al. 2000).

New record. **NEW BRUNSWICK**: 1♀, St. John, Rockwood Pk., 5.viii.1954 (J. F. Brimley) [CNC].

Family RHOPALIDAE*Boisea trivittata* (Say)

Illustrated by Blatchley (1926), Froeschner (1942), and Henry (1988), the box-elder plant bug is widely distributed in North America, although early western records refer to *B. rubrolineata* Barber (Barber 1956; Henry 1988).

New record. **WYOMING**: 3♀, Ft. Laramie, 25.x.1973 (W. J. M.) [RBCM].

Rhopalus tigrinus (Schilling)

First reported from eastern North America, *R. tigrinus* was keyed and illustrated by Hoebeke and Wheeler (1982). This species occurs in many western states (Wheeler and Hoebeke 1999) and in the southern interior of British Columbia (Scudder 2007).

New records. **IDAHO**: 1♀, Canyon Co., Parma, Sample #F11, 17.vii.2000, Mary Gardiner MS thesis voucher specimen: collected from Hop-*Humulus lupulus* (Urticales: Cannabaceae) [WFBM]; 1♂, Canyon Co., Parma, sample #F52, 20.viii.2001, Mary Gardiner MS thesis voucher specimen: collected from Hop-*Humulus lupulus* (Urticales: Cannabaceae); [green label] 'Lygaeidae unident. Sp. #2' [WFBM]; 1♀, Latah Co., Moscow, 20.vi.1963 (D. J. Schotzko) [WFBM]; 1♀, Latah Co., Kendrick, 3 mi SE, 23.iv.1981 (D. J. Schotzko) [WFBM]; 1♂, Latah Co., Kendrick, 3 mi E, 14.v.1982 (D. J. Schotzko) [WFBM]; 1♂ 1♀, Latah Co., Genesee, 1.5 mi N, UI Kambitsch Farm, ex *Brassica napus*, 25.vii.2001 (A. A. Stehr) [WFBM]; 1♂ Latah Co., Moscow, 5 mi E, Robinson Park, 22.iv.2005 (Brent J. Werner) [WFBM].

Stictopleurus knighti Harris

Redescribed and keyed by Göllner-Scheiding (1975), this species was reported in Canada from Quebec by Roch (2008). In the United States, it is recorded from Michigan, Minnesota, and Wyoming (Henry 1988).

New record. **NEW BRUNSWICK**: 1♀, Restigouche Co., Jacquet River Gorge PNA, 47.8207°N 65.9961°W, 25.vi.2008 (R. P. Webster) [NBM 030638].

Family ARTHENEIDAE*Chilacis typhae* (Perris)

An alien species in North America, *C. typhae* was illustrated by Wheeler and Fetter (1987), and is known to be widely distributed both in Canada and the United States. Although already recorded from many states (Wheeler and Fetter 1987; Wheeler and Stoops 1999; Wheeler 2002), this is the first report from Idaho.

New record. **IDAHO**: 1♂, Latah County, Moscow, Paradise Creek, 1.v.2005 (Brent J. Werner) [WFBM].

Family BERYTIDAE

Berytinus minor (Herrich-Schaeffer)

This alien species in Canada was keyed by Scudder (1991), and the characteristics of the head were illustrated. It is also keyed and illustrated by Henry (1997). Until now, the species has been known only from Ontario eastwards to Newfoundland, in Canada (Scudder and Footitt 2006). Wheeler (1970, 1971) gives details of the occurrence and biology of the species in North America.

New record. **BRITISH COLUMBIA**: 1♂, Victoria, University of Victoria, 28.ix.2009 (Clarissa Bruckal) [RBCM].

Family CYMIDAE*Cymus luridus* Stål

The *Cymus* species were keyed by Torre-Bueno (1946) and Hamid (1975). *Cymus luridus* is a Nearctic species, widely distributed in North America (Ashlock and Slater 1988).

New record. **MONTANA**: 1♀, Lake Co., Swan Lake, flight, 22.vii.1962 [WFBM].

Family GEOCORIDAE*Geocoris atricolor* Montandon

Keyed by Torre-Bueno (1946), *G. atricolor* in Canada is recorded from British Columbia, Alberta, and Saskatchewan (Scudder 2010a); in the United States, it is confined to the west (Ashlock and Slater 1988).

New record. **SOUTH DAKOTA**: 1♀, Badlands, 13.ix.1963 (G. G. E. Scudder) [Scudder Coll.].

Geocoris howardi Montandon

Keyed and illustrated by Readio and Sweet (1982). This species is widely distributed across boreal North America.

New records. **IDAHO**: 1♀, Canyon Co., Parma, alfalfa, 9.viii.1971 (N. D. Waters) [WFBM]; 1♀, Latah Co., Moscow-Manis Lab., 10.ix.1984 (D. J. Schotzko [WFBM].

Geocoris pallens Stål

Geocoris pallens was keyed and illustrated by Readio and Sweet (1982). They note that this species has been collected from most of the western United States and has a range eastwards to Indiana, Illinois, Missouri, and Arkansas. In Canada, it has long been known from British Columbia (Torre-Bueno 1925, 1946; Downes 1927) and was recently recorded from Saskatchewan (Scudder 2010a).

New records. **ALBERTA**: 1♂, Brocket, 19 km N, 49°43'N 113°45'W, 1410m, pan trap collection Code No. D1-10-Y1, 6-10.viii.1998 (K. White) [CNC]. **WASHINGTON**: 1♀, Maryhill, on alfalfa, 23.iv.1938 (Gray & Schuh) [OSU]; 1♀, Oroville, E. Osoyoos L., 48°58'N 119°25'W, Purshia assoc., AN BGxh1, Pitfall trap O5-2, 9.viii-10.ix.1995 (G. E. Scudder) [UBC].

Family LYGAEIDAE*Lygaeospilus brevipilus* Scudder

Described, illustrated and keyed by Scudder (1981), *L. brevipilus* is also keyed by Slater (1992). To date, it has been recorded from only British Columbia. The records below constitute a new species to the United States.

New records. **CALIFORNIA**: 1♀, Siskiyou Co., Bartle, 1 mi SE, 8-10.vi.1974 (J. Doyen) [UCB]. **IDAHO**: 1♀, Moscow, 2560', 21.v.1928 [WFBM]. **OREGON**: 1♂ 2♀, Wallowa Co., Enterprise, 5 mi N, 3760', roadside sweeping, 30.vi.1960 (J. D. Lattin) [OSU].

Lygaeus truncatulus Stål

Keyed by Brailovsky (1978) and Slater (1992), this western species has been reported to date from Arizona, California, and Mexico, south to South America (Ashlock and Slater 1988).

New records. **OREGON**: 1♂, Klamath County, mouth Williamson Cr., on *Asclepias*, 17.vi.1958 (Joe Schuh) [OSU]; 1♂, Klamath L., Eagle Ridge, 27.v.1924 (C. L. Fox) [CAS].

Melacoryphus lateralis (Dallas)

Melacoryphus lateralis is keyed by Slater (1992). It is a western North American species also recorded from Mexico (Ashlock and Slater 1988).

New records. **NEBRASKA**: 2♂ 2♀, Lincoln Co., North Platte, 27.vii.1978 (H.W. Homan) [WFBM]. **NEW MEXICO**: 1♀, Doña Ana Co., Las Cruces, 7.x.1991 (J. B. Johnson) [WFBM]. **NEVADA**: 1♂, Lincoln Co., Pioche, Penstemon, 9.vii.1965 (W. F. Barr) [WFBM]. **OREGON**: 1♀, Warner V., 15.viii.1934 (McLeod) [CAS].

Melanopleurus belfragei Stål

This species, keyed by Slater (1992), has been reported from Arizona, California, New

Mexico, Texas, and Mexico (Ashlock and Slater 1988).

New record. **NEVADA**: 2♀, Clark Co., Kyle Canyon, Encelia, 19.vi.1967 (S. M. Hogue) [WFBM].

Neacoryphus bicrucis (Say)

Keyed by Slater (1992), *N. bicrucis* is widely distributed in North America, and occurs from Mexico to Brazil (Ashlock and Slater 1988).

New records. **OREGON**: 4♂ 3♀, Detroit, Willamette Nat. Forest, Humbug Forest Camp 44, 17.vii.1941 (H. & F. Daniels) [WFBM]. **WASHINGTON**: 1♀, Whitman Co., Wawawai, 24.x.1989 (R. J. Sawby) [WFBM].

Oncopeltus fasciatus (Dallas)

This well-known migratory lygaeid, keyed by Slater (1992), is widely distributed in North and South America, but is not recorded from New Mexico by Ashlock and Slater (1988).

New records. **NEW MEXICO**: 2♀, Hidalgo Co., Rodeo, 1 mi S., 26.vi.1969 (D. E. Foster, L. S. Hawkins, R. L. Penrose) [WFBM]; 1♂, McKinley Co., Zuni, 11 mi NE, *Asclepias*, 23.vii.1969 (D. E. Foster, R. L. Penrose) [WFBM].

Family ORSILLIDAE

Belonochilus numenius (Say)

This species was keyed by Blatchley (1926) and Torre-Bueno (1946). Until now, in Canada, *B. numenius* has been recorded only in Ontario (Maw et al. 2000), although it is widely distributed in the United States (Ashlock and Slater 1988). The seasonal history, habits, and immature stages of this species were described by Wheeler (1984). The usual host is sycamore or American plane tree (*Plantanus occidentalis* L.). The following record for British Columbia evidently represents an alien introduction into this province.

New record. **BRITISH COLUMBIA**: 3♂ 2♀, Kelowna, 49°53'16.84"N 119°25'23.75"W, 1245 ft., on London plane, 9.ix.2011 (Susanna Acheampong) [CNC].

Neortholomus scolopax (Say)

Keyed by Hamilton (1983), *N. scolopax* is distributed across southern Canada, the

continental United States, Mexico and Guatemala.

New records. **OREGON**: 6♂ 3♀, Corvallis, on strawberry, 21.vii.1935 (K. Gray) [OSU]; 1♀, Maclean, 7.iii.1933 (J. Schuh) [OSU]; 1♀, Peoria, 24.vii.1928 (J. E. Davis) [OSU].

Nysius insoletus Barber

Described and keyed by Barber (1947), *N. insoletus* has been recorded from only Colorado and Utah (Ashlock and Slater 1988). Idaho specimens have been compared with paratypes from Utah [USNM].

New record. **IDAHO**: 2♀, Bingham Co., SE of Blackfoot, 12.vii.1956 (H. W. Smith) [WFBM].

Nysius raphanus Howard

Keyed by Barber (1947), *N. raphanus* occurs widely in North America, Mexico, and the West Indies (Ashlock and Slater 1988). It is illustrated by Baranowski and Slater (2005). Previous to the record below, it has not been reported from Washington State.

New record. **WASHINGTON**: 1♂, Franklin Co., Palouse Falls, 13.viii.1971 (A. R. Gittins) [WFBM].

Nysius tenellus Barber

Described and keyed by Barber (1947), *N. tenellus* occurs widely in western North America (Ashlock and Slater 1988). In Canada, it has been reported previously from British Columbia and Saskatchewan (Scudder 2010a).

New record. **ALBERTA**: 1♂, Medicine Hat, 6.vi.1932 (O. Bryant) [CAS].

Family OXYCARENIDAE

Crophius albidus Barber

Described and keyed by Barber (1938), *C. albidus* to date has been recorded from only Utah. The Idaho specimen has been compared with a photograph of a male paratype from Mt. Pleasant, Utah [USNM].

New record. **IDAHO**: 1♀, Owyhee Co., Hot Springs, 16.vi.1961 (M. M. Furniss) [WFBM].

Crophius angustatus Van Duzee

Described and illustrated by Van Duzee (1910), *C. angustatus* was keyed by Barber (1938). It is a North American species

reported from across Canada (Maw et al. 2000; Scudder 2010a) and, in the United States, from California, Colorado, Oregon, and Utah (Ashlock and Slater 1988).

New records. **IDAHO**: 1♂, Big Wood Riv., Stanton Crossing, 10.viii.1930 (J. C. Chamberlin) [CAS]; 1♂, Camas Co., Fairfield, 23 mi E, 24.vi.1966 (W. F. Barr) [WFBM]; 1♂, Custer Co., Leslie, 10 mi N, Bear Cr. Camp, 19.vii.1965 (R. L. Westcott) [WFBM]; 1♂ 1♀, Custer Co., Morgan Creek, 29.vi.1964 (R. L. Westcott) [WFBM]; 1♀, Nez Perce Co., Lewiston, 7 mi E, collected on *Salix* (D. A. Barstow) [WFBM] (previously det. *C. scabrosus* by Froeschner 1967). **MONTANA**: 1♀, Flathead Co., Swan Lk. G. S., sweeping marsh, 22.vii.1963 [WFBM]. **WASHINGTON**: 1♀, Cle Elum, 20.vi.1954 (B. Malkin & D. Boddy) [CAS].

Crophius bohemani (Stål)

Keyed by Barber (1938), this species is widely distributed in the western United States (Ashlock and Slater 1988). In Canada, it is recorded from British Columbia and Saskatchewan.

New records: **WASHINGTON**: 1♀, Klickitat Co., Lyle, 5 mi NE, 5.v.1972 (Oman) [OSU]; 1♀, Pierce Co., Fort Lewis, 5.v.1946 (P. H. Arnaud) [CAS].

Crophius impressus Van Duzee

Described and illustrated by Van Duzee (1910), *C. impressus* was keyed by Barber (1938). To date, the species has been recorded from only California and Utah (Ashlock and Slater 1988).

New records. **NEVADA**: 1♀, Nixon, 30.vi.1927 (E. P. Van Duzee) [CAS]; 1♀, Reno, 27.vi.1927 (E. P. Van Duzee) [CAS]. **OREGON**: 1♀, Benton Co., Corvallis, 4.vi.1957 (J. D. Lattin) [OSU]; 1♀, Benton Co., Granger, on thimbleberry, 11.v.1960 (E. A. Dickason) [OSU]; 1♀, Corvallis, 11.vi.1925 (E. P. Van Duzee) [CAS]; 2♂ 2♀, Josephine Co., Deer Crk., Selma, 1 mi S, 1325', 29.v.1960 (J. D. Lattin) [OSU]; 1♂, Monroe, 21.v.1931 (Noal P. Larson) [USNM]; 1♀, Portland, 10 mi S, sweeping along highway, 22.v.1959 (S. Radinovsky) (J. D. Lattin collection) [OSU]; 1♀, Talent, under c.m. bands, 26.i.1931 (L. G. Gentner) [OSU].

Crophius scabrosus (Uhler)

Keyed by Barber (1938), *C. scabrosus* has been recorded from Arizona, California, Colorado, Idaho, New Mexico, Nebraska, Utah, and Mexico (Ashlock and Slater 1988).

New records. **OREGON**: 1♂ 6♀, Harney Co., Andrews, 6 mi N, Alvord Desert, 11.vii.1968 (Oman) [OSU]; 2♀, Harney Co., Hdq. Squaw Butte Exp. Sta., 3 mi S, ex. sagebrush, 6.vii.1977 (J. D. Lattin) [OSU].

Family PACHYGRONTHIDAE

Phlegyas annulicrus Stål

Keyed by Slater (1955), *P. annulicrus* has a wide distribution in the United States (Ashlock and Slater 1988). In Canada, it is known from only British Columbia (Maw et al. 2000).

New record. **IDAHO**: 1♂, Owyhee Co., Snake River, Bruneau, 5 mi NE, 19.vi.1972 (W. F. Barr) [WFBM].

Family RHYPAROCHROMIDAE

Antilocoris pilosulus (Stål)

Keyed by Barber (1952), *A. pilosulus* is widely distributed in the eastern United States (Ashlock & Slater 1988).

New record. **GEORGIA**: 1♀, Rabun Co., Tally Mill Crk., at Hwy. 28, 18.v.1986 (A. Smetana) [CNC].

Atrazonotus umbrosus (Distant)

The genus *Atrazonotus* was described and keyed by Slater and Ashlock (1966). *Atrazonotus umbrosus* is widely distributed in North America (Ashlock and Slater 1988).

New records. **MINNESOTA**: 1♀, Olmsted Co., Chatfield, 6 mi E, 17.v.1967 (J. R. Powers) [UCB]. **WASHINGTON**: 1♂ 1♀, Vancouver, ex bark mulch, x.1981 (Mike Hart) [OSU].

Drymus crassus Van Duzee

Recently keyed by Scudder et al. (2012), *D. crassus* is restricted in Canada to the eastern provinces (Maw et al. 2000).

New record. **NEW BRUNSWICK**: 1♂, Queens Co., Cranberry Lake Protected Natural Area, 46.117°N 65.608°W, 85m, in leaf litter, 6.viii.2009 (D. F. McAlpine, P. P. Webster, Aaron Fairweather) [NBM 028314].

Eremocoris borealis (Dallas)

Sweet (1977) clarified the identity of this species and keyed the species of *Eremocoris*

of North America east of the 100th meridian. The hind tibia of *E. borealis* is sparsely pilose, with the setae shorter than the moveable spines. The labium also attains only the metasternum and not the abdomen, as is the case in *E. ferus* (Say).

New records. **MASSACHUSETTS**: 1♀, Beach Bluff, ocean beach, 4.vii.1915 (H. M. Parshley) [CAS]. **NEW YORK**: 1♀, Ithaca, 23.v.1967 (A. Greene) [WSU].

Eremocoris ferus (Say)

The identity of *E. ferus* was clarified and the species keyed by Sweet (1977). The hind tibia has setae that are much longer than the moveable spines. Sweet (1977) indicated that old northern records probably refer to *E. borealis* and that records west of the 100th meridian refer to a complex of undescribed species. However, *E. ferus* has been recorded from British Columbia and Saskatchewan (Scudder 2010a).

New records. **IDAHO**: 2♂ 1♀, Custer, Co., Challis, 14.5 mi N, leaf litter, Ber. funnel. 17.iii.1981 (F. W. Merichel) [WFBM]. **WASHINGTON**: 1♂, Pullman, VI [WSU].

Eremocoris inquilinus Van Duzee

Eremocoris inquilinus was keyed by Torre-Bueno (1946). In addition to lacking long outstanding setae on the hind tibia, the species's corium and clavus are uniform ferruginous, and its membrane is dark brown without an obvious pale spot, but quite ferruginous adjacent at the base. To date, the species has been reported from only California.

New records. **ARIZONA**: 1♂, Sta. Rita Mts., 30.ix.1936 (Bryant Lot 51) [CAS]; 1♀, *id.*, 25.iii.1937 (Bryant Lot 9) [CAS].

Eremocoris obscurus Van Duzee

Eremocoris obscurus was keyed by Torre-Bueno (1946). *Eremocoris obscurus* lacks long erect setae on the hind tibia, the apical two-thirds of the insect's corium is uniform dark brown, the membrane has a small, elliptical pale spot, and the fore femora have two large spines. In the male, the anterior lobe of the pronotum is markedly convex. To date, *E. obscurus* has been recorded from only British Columbia, California, and Idaho.

New records. **OREGON**: 1♀, Klamath Co., La Pine, 13 mi S, T24S, R11E, S18, 12.ix.1958 (Gerald F. Kraft) [OSU]; 1♀,

Upper Klamath Lk., 3 m Cr., 30.v.1960 (Joe Schuh) [OSU]; 1♀, Wasco Co., Bear Spr., 5.vi.1962 (K. M. & D. M. Fender) [OSU]. **WASHINGTON**: 1♂, Columbia Co., Sheep Creek nr. Tucannon R., 6 mi S Tucannon RS, east of Dayton, 22.v.1982 (W. J. Turner) [WSU]; 1♀, Puyallup, 30.iv.1935 (Wm. W. Baker) [WSU]; 1♀, Tampico, 6.iii.1931 (A. R. Rolfs) [WSU]; 1♂, *id.*, 7.v.1932 (A. R. Rolfs) [WSU].

Eremocoris semicinctus Van Duzee

Eremocoris semicinctus was keyed by Torre-Bueno (1946) and by Walley (1929) as a new species (= *E. melanotus* Walley **syn. nov.**). *Eremocoris melanotus* was described from British Columbia, and examination of the types shows these two species are conspecific. Both have previously been recorded from Idaho. *Eremocoris semicinctus* was described from California.

New records. **WASHINGTON**: 1♂, Chelan Co., Wenatchee, 5 mi SSW, Squillchuck Crk. at Wenatchee Hts. Rd., 1800 ft., 9.v.1981 (W. Turner) [WSU]; 1♀, *id.*, 14.v.1983 (W. J. Turner) [WSU]; 1♀, Cle Elum, 1.v.1932 (J. Wilcox) [WSU]; 1♂, *id.*, 21.v.1933 (Wm. W. Baker) [WSU]; ♀, *id.*, 21.v.1935 (Wm. W. Baker) [WSU]; 1♂ 1♀, Spokane Co., Spokane, Upriver Rd., Minihaha Park, 1.iv.1983 (Alan Mudge) [WSU].

Eremocoris setosus Blatchley

Keyed by Torre-Bueno (1946) and Sweet (1977), *E. setosus*'s entire body and legs are densely pilose with long erect setae, the hemelytra are uniformly dark brown, the antennae and legs are dark brown, and the fore femora are armed beneath with two major spines. The insect's membrane is dark brown with an elliptical pale spot with diffuse margins adjacent to the apical angle of the corium. Previous records are from the eastern United States (Ashlock and Slater 1988) and from Ontario and Quebec in Canada (Paiero et al. 2003). The species evidently has not previously been reported from western Canada and the western United States.

New records. **ALBERTA**: 1♂ 1♀, W. of Pembina R., nr. Fawcett, 3-4.vi.1957 (George E. Ball) [UASM]. **ARIZONA**: 1♂ 3♀, Sta. Catalina Mts., 15.vii.1938 (Bryant Lot 21) [CAS]; 2♀, *id.*, 15.vii.1938 (Bryant Lot 43) [CAS]; 1♂, *id.*, 15.x.1938 (Bryant Lot 21)

[CAS]; 1♀, *id.*, 25.vi.1940 (Bryant Lot 23) [CAS]; 2♀, *id.*, vi.1940 (Bryant Lot 23) [CAS]; 1♂ 1♀, *id.*, 25.ix.1940 (Bryant Lot 9700) [CAS]. COLORADO: 1♂, Boulder, March (T. D. A. Cockerell) [CAS].

Ligyrocoris delitus Distant

Keyed by Barber (1921) and Sweet (1986), *L. delitus* has been recorded from Arizona and California, and from Mexico to Central America (Ashlock and Slater 1988).

New record. **NEW MEXICO**: 1♂, Deming, 5 mi NE, *Asclepias*, 5.vii.1958 (W. F. Barr) [WFBM].

Ligyrocoris diffusus (Uhler)

Keyed by Barber (1921) and Sweet (1986), *L. diffusus* is widely distributed in North America (Ashlock and Slater 1988), and across Canada (Maw et al. 2000), although not previously recorded from Oregon and Prince Edward Island.

New record. **OREGON**: 1♀, Summit Prairie, 3.viii.1935 (Joe Schuh) [OSU]; 1♀, *id.*, 23.vii.1939 (Schuh & Gray) [OSU]; 1♂, *id.*, 9.viii.1939 (Schuh & Gray) [OSU]. **PRINCE EDWARD ISLAND**: 1♀, Wood Island, ix.1927 [CNC].

Malezonotus arcuatus Ashlock

Described and keyed by Ashlock (1958), this species so far has been reported from only British Columbia and Washington.

New record. **OREGON**: 1♂, Linn Co., Monument Peak G.S., Sec. 21, T10S, R4E, 16.vii.1974 (W. F. Barr) [WFBM].

Myodocha serripes Olivier

Keyed most recently by Cervantes (2005), *M. serripes* is widely distributed in eastern North America, but to date does not appear to have been recorded from Delaware (Ashlock and Slater 1988).

New record. **DELAWARE**: 1♀, Newcastle Co., Newark, 2 mi N on Papermill Rd., 31.vii.1991. (P. W. Gothro) [WFBM].

Ozophora occidentalis Slater

Described and keyed by Slater (1988), *O. occidentalis* so far has been recorded from only British Columbia, California, Nevada, and Oregon. Idaho specimens were compared with paratypes from British Columbia.

New records. **IDAHO**: 1♂ 1♀, Idaho Co., Skookumchuck Cr., cottonwood leaf litter, Ber. funnel, 9.ii.1981 (F. W. Merichel) [WFBM]; 1♀, Latah Co., Moscow, Berlese sample, maple leaf litter, 4.i.1963 (W. F. Barr, A. R. Gittins) [WFBM]; 3♀, Nez Perce Co., Arrow Jct. at Hwy. 3 & 12, B.f. *Populus*/Locust litter, 25.i.2005 (F. W. Merichel) [WFBM].

Peritrechus convivus (Stål)

Keyed most recently by Scudder (1999), *P. convivus* is a Holarctic species widely distributed in North America (Scudder 1999).

New record. **MINNESOTA**: 1♀, Clay Co., Moorehead, 3.v.1961 (B. Wermager) [UCB].

Peritrechus fraternus Uhler

Keyed most recently by Scudder (1999), *P. fraternus* is widely distributed in North America (Ashlock and Slater 1988), but does not appear to have been recorded from Ohio.

New record. **OHIO**: 1♀, Columbus, 19.v.1943 (H. W. Smith) [WFBM].

Pseudopamera nitidula (Uhler)

Keyed by Barber (1921) and Torre-Bueno (1946) as *Ligyrocoris* (*Neoligyrocoris*) *nitidulus* Uhler, this species occurs in the western United States (Ashlock and Slater 1988), but has not previously been reported from Idaho.

New record. **IDAHO**: 1♂, Owyhee Co., Hot Cr. Falls, 9.viii.1969 (W. F. Barr) [WFBM].

Scolopostethus diffidens Horváth

Scolopostethus diffidens was keyed by Torre-Bueno (1946). In *S. diffidens*, the clavus has more than three regular rows of punctures, the terminal two segments and apical part of the second antennal segment are black, and the membrane is fuscous with a distinct round white spot. In macropterous specimens, the veins are also pale, especially basally. *S. diffidens* is widely distributed in North America (Ashlock and Slater 1988) and was recently recorded from Nevada (Scudder 2010b).

New records. **OREGON**: 2♂, Benton Co., Mary's Pk., 14 mi W Corvallis, Parker Cr. Falls, 2800' elev., in moss, 28.ix.1960 (J. D. Lattin) [OSU]; 8♂ 7♀, Benton Co., Grass Mt., 5 mi NW Alsea, 3600', on ground in meadow,

3.x.1960 (J. D. Lattin) [OSU]; 1♂ 2♀, Benton Co., N. Fk. Alsea R., 8 mi E Alsea, moss on fallen log, 12.i.1961 (J. D. Lattin) [OSU]; 1♀, Clackamas Co., Portland, 3 mi S, leaf litter, 26.xii.1959 (S. Radinovsky) [OSU]; 1♂, Cannon Beach, 14.vi.1927 (E. C. Van Dyke) [CAS]; 2♀, Clatsop Co., J. J. Astor Exp. Stn., moss on logs, 29.ix.1960 (E. Dickason) [OSU]; 1♀, Curry Co., Brookings, 9 mi N, ex. ground litter, 9.ix.1958 (J. Capizzi) [OSU]; 1♀, Douglas Co., Glide, 20 mi ENE, 2450', lichen & moss, 23.iii.1961 (D. Fellin) [OSU]; 2♀, Jackson Co., Upper Dead Indian Soda Springs, Eagle Point, 23 mi ESE, 2650', 21.v.1960 (J. D. Lattin) [OSU]; 20♂ 12♀, Jackson Co., Upper Dead Indian Soda Spr., Eagle Pt., 23 mi SE, 2650' ex. moss around spring, 21.v.1960 (J. D. Lattin) [OSU]; 1♂, Klamath Co., Mare's Egg Spring, 30.v.1960 (Joe Schuh) [OSU]; 1♂ 1♀, Lane Co., Florence, 5 mi N, sand dune litter, 5.vii.1959 (S. Radinovsky) [OSU]; 1♂ 2♀, Lane Co., Florence, 15.vii.1959 (S. Radinovsky) [OSU]; 2♀, Lincoln Co., Waldport, 13.vi.1936 (Van Dyke collection) [CAS]; 1♀, Lincoln Co., Waldport, 2.5 mi N, 29.x.1970 (Oman & Viraktamath) [OSU]; 1♂ 4♀, Linn Co., Sweet Home, 32 mi E, 3800', Rhododendron litter, 25.iii.1960 (J. D. Lattin) [OSU]; 2♂ 2♀, *id.*, *Manzanita* litter, 25.iii.1961 (J. D. Lattin) [OSU]; 2♂ 2♀, Linn Co., Cascadia St. Pk., Sweet Home, 14 mi E, leaf & moss litter, 26.iii.1960 (Radinovsky) [OSU]; 7♂ 10♀, Linn Co., Longbow Camp, Sweethome, 25 mi E, leaf & moss litter, 26.iii.1960 (Radinovsky) [OSU]; 4♂, Linn Co., Sweet Home, 8 mi E, moss nr. River, 18.vi.1960 (J. D. Lattin) [OSU]; 1♂ 1♀, Marion Co., Silver Cr. Falls, ground litter, 26.iv.1959 (S. Radinovsky) [OSU]; 1♀, Tillamook Co., Oceanside, ½ mi S, 3.x.1972 (Oman) [OSU]; 2♂, Tillamook Co., Woods, salal-huckleberry, 23.x.1955 (K. M. Fender) [OSU]; 1♂, Yamhill Co., Bald Mt., 4.vii.1958 (K. M. Fender) [OSU].

In addition to the above, G. G. E. Scudder examined 26♂ 31♀ specimens (mostly singletons) in the OSU collection from the same counties in Oregon.

Scolopostethus thomsoni Reuter

This Holarctic species is easily recognized by the double row of spines ventrally on the fore femora. It occurs across Canada (Maw et al. 2000) and is widely distributed in the

United States (Ashlock and Slater 1988). It is recently recorded from Nevada (Scudder 2010b).

New record. **WYOMING**: 1♀, YNP, Old Faithful, 15.vii.1956 (Gary Debel) [UCBJ].

Sisamnes claviger (Uhler)

Keyed by Barber (1953), *S. claviger* is widely distributed in North America (Ashlock and Slater 1988), and recently was recorded from Saskatchewan (Scudder 2010a).

New records. **CALIFORNIA**: 1♂ 1♀, Siskiyou Co., Lava Beds Nat. Mon., Mammoth Crater, under *Horkelia* sp., 13.viii.1961 (Joe Schuh) [OSU]. **WASHINGTON**: 4♂, Oroville, E. Osoyoos L., 48°58'N 119°25'W, *Purshia* assoc., AN BGxh1, Pitfall trap 04-1, 5-30.v.1994 (G. G. E. Scudder) [UCBJ]; 5♂ 1♀, *id.*, Pitfall trap 04-3; 8♂, *id.*, Pitfall trap 04-5; 3♂, *id.*, Pitfall trap 05-1; 2♂ 1♀, *id.*, Pitfall trap 05-2; 18♂ 3♀, *id.*, Pitfall trap 05-4 [AMNH, CAS, OSU, USNM, WSU, Scudder Coll.]; 2♂, *id.*, Pitfall trap 02-3, 5.vii-2.viii.1994 (G. G. E. Scudder) [Scudder Coll.]; 1♂, *id.*, Pitfall trap 05-2, 5.vii-2.viii.1994 (G. G. E. Scudder) [Scudder Coll.].

Sphragisticus nebulosus (Fallén)

Sphragisticus nebulosus is a Holarctic species keyed by Torre-Bueno (1946). It is easily recognized by the explanate lateral margin of the pronotum with a few punctures from which arise upstanding black bristles, and with a scutellum apically with a pale Y-shaped flavescent mark. *S. nebulosus* occurs across Canada (Maw et al. 2000), is widely distributed in the United States, and was recently reported from Vermont (Scudder 2010b).

New records. **ARIZONA**: 1♀, Cochise Co., Portal, 5 mi W, 28.vi.1958 (W. F. Barr) [WFBM]. **WASHINGTON**: 1♀, Tonasket, 4 mi S, attracted by black light, 1.viii.1962 (J. E. Halfhill) [WFBM].

Family ACANTHOSOMATIDAE

Elasmostethus cruciatus (Say)

Keyed by Torre-Bueno (1939) and Thomas (1991), *E. cruciatus* lacks a row of black spots laterally on the abdominal sternum. It occurs across Canada (Maw et al. 2000), but this is the first Yukon record. Other *Elasmostethus* specimens previously studied from the Yukon have black spots laterally on the abdominal

sternum; they are *E. interstinctus* (L.) (Scudder 1997).

New record. **YUKON TERRITORY**: 1♀, Alaska Hwy. km 1403 at Judas Cr. Cpgrd., 60°23'N 134°08'W, flying along rd., 11.vi.1980 (ROM Fld. Pty.) [ROM#800017f].

Family CYDNIDAE

Sehirus cinctus cinctus (Palisot)

Keyed by Froeschner (1960), this subspecies characteristically lacks a pale spot on the corium. *S. cinctus cinctus* occurs throughout the eastern United States and in New Mexico, Texas, and Mexico (Froeschner 1988b). The record below for Ontario represents a new taxon for Canada, as most other specimens of this species across Canada are *S. cinctus albonotatus* Dallas (Maw et al. 2000).

New record. **ONTARIO**: 1♀, Pt. Pelee, 2.vi.1982 (Randy Young) [CNC].

Family PENTATOMIDAE

Dendrocoris pini Montandon

Keyed by Nelson (1955), *D. pini* occurs in the western and southwestern United States (Nelson 1955) and in British Columbia (Scudder 1985).

New records. **NEVADA**: 1♂, Clark Co., Mt. Springs Summit, 5400', 26.v.1961 (R. C. Bechtel) [OSU]; 1♀, Lincoln Co., Pioche, *Pinus monophylla*, 22.v.1961 (R. C. Bechtel) [OSU].

Thyanta accerra McAtee

Keyed by McPherson (1982), *T. accerra* is widely distributed in the United States (Froeschner 1998c), but in Canada, it is reported from only Manitoba, Ontario, and Quebec (Maw et al. 2000).

New record. **SASKATCHEWAN**: 1♂, near Clearwater Lake, 60°52.464'N 107°54.444'W, 18.vii.2012 (J. E. Swann & D. R. Edwards) [DBUC].

Family SCUTELLERIDAE

Eurygaster alternata (Say)

Eurygaster alternata was keyed by McPherson (1982). In *E. alternata*, the antero-lateral margins of the pronotum are slightly concave, and the base of the scutellum typically has a pair of well-developed flavescent calloused spots. Lattin (1964) noted that this species occurs across the entire

northern United States and southern Canada, although it does appear to be localized. The species is not recorded from either Idaho or Vermont by Froeschner (1988d).

New records. **IDAHO**: 1♀, Bovill, 17.vi.1911 [LEM]. **VERMONT**: 1♀, Manchester, 1.vii.1965 (W. Boyle) [LEM].

Eurygaster amerinda Bliven

Eurygaster amerinda was keyed by McPherson (1982). In *E. amerinda*, the antero-lateral margins of the pronotum are arcuate or broadly convex, and the base of the scutellum typically lacks a pair of flavescent calloused spots. Although Froeschner (1988d) reports the species from only California and Illinois, Lattin (1964), in Plate 13, shows it to be widely distributed across North America. Maw et al. (2000) report the species across Canada, from the Northwest Territories to Quebec. The following records are in addition to those in Froeschner (1988d) and Maw et al. (2000).

New records. **COLORADO**: 1♀, Boulder, vii.1927 (D. Stoner) [LEM]. **MAINE**: 1♂, 1♀, Peaks Is., 26.vii.1920 (G. A. Moore); 1♂, *id.*, 4.viii.1920; 1♀, *id.*, 25.vii.1925; 1♂, *id.*, 23.viii.1927; 1♀, *id.*, 23.vii.1933; 1♀, *id.*, 27.vii.1935; 1♂, *id.*, 11.viii.1936; 1♂, *id.*, 2.viii.1937; 1♀, *id.*, 15.vii.1938; 1♀, *id.*, 31.vii.1939 (G. A. Moore) [LEM]. **MICHIGAN**: 1♂, Douglas Lake, vii.1917 (D. Stoner) [LEM]. **MONTANA**: 1♀, Missoula, 12.vi.1985 (G. G. E. Scudder) [USNM]. **NOVA SCOTIA**: 1♂, Falmouth, 20.v.1984 (G. G. E. Scudder) [CNC]. **TEXAS**: 2♂, Houston, 19.viii.1965 (W. Hoek, J. Lorrity) [LEM]. **UTAH**: 2♂ 4♀, Iron Co. [LEM]. **WASHINGTON**: 1♂, Pullman, vi.1920 (G. A. Pearson) [LEM]; 1♀, *id.*, v.1921 (Adah Procter) [LEM]; 1♀, *id.*, vi.1921 (H. Eggerth) [LEM]; 1♂ 2♀, Pullman [LM].

Vanduzeeina borealis Van Duzee

Keyed by Usinger (1930) and Lattin (1964), *V. borealis* is reported from Alberta, British Columbia, California, Illinois, Ontario, South Dakota, and the Yukon (Froeschner 1988d; Maw et al. 2000).

New record. **SASKATCHEWAN**: 1♀, Prince Albert N.P., *Picea glauca*, 22.vi.1960 (F.I.S. W60-1203-05) [JBWM].

Family THYREOCORIDAE

Galgupha atra Amyot & Serville

Keyed by McPherson (1982), *G. atra* is widely distributed in North America (Froeschner 1988e). In Canada, it has been reported from Saskatchewan to Newfoundland

(Maw et al. 2000), but it has not been recorded from New Brunswick to date.

New record. **NEW BRUNSWICK:** 1♀, St. J[ohn], 15.v.1899 (W. M.) [NBM].

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SCIENTIFIC NOTE

Metopoplax ditomoides* (Costa) (Hemiptera: Lygaeoidea: Oxycarenidae): First Canadian Record of a Palearctic Seed Bug*A.G. WHEELER, JR.¹ and E. RICHARD HOEBEKE²**

Metopoplax ditomoides (Costa) is a mainly west European and north African (Mediterranean) species (Péricart 1999) that has expanded its range in the last half century, as evidenced by comparing the distributions listed by Slater (1964) and Péricart (2001). First taken in England in 1952 (Woodroffe 1953a, b), this immigrant bug was not recorded again in Britain until breeding populations apparently became established in the 1990s; by the late 1990s, "prodigious numbers" were observed (Kirby *et al.* 2001). In continental Europe, *M. ditomoides* has spread north from the Mediterranean region (Rabitsch 2008) and probably also has been transported in shipments of plant material (Deckert 2004). This seed bug has been detected recently in several countries, including Belgium (Bruers and Viskens 1997), and has become more common in the Netherlands (Aukema 2003).

The first North American records were from Oregon (Benton, Lane, Marion, and Polk counties), where adults were collected from hazelnut (*Corylus avellana* L.) orchards and found swarming in houses (Lattin and Wetherill 2002). *Metopoplax ditomoides* soon was reported from California (Alameda, Marin, Solano, and Sonoma counties), with the first collections at Vernon (Sonoma Co.) in 2002 (Gaimari 2005), and from Washington State based on adults taken in a house at Lynden (Whatcom Co.) in 2006 (LaGasa and Murray 2007). Lynden is within about 6 km of the Canadian border south of Aldergrove, British Columbia.

Metopoplax ditomoides (Figure 1) can readily be distinguished from other Nearctic oxycarenids. The antenniferous tubercles are prominent and rounded anteriorly; the clypeus is produced and spatulate; the head, pronotum,

and scutellum are black, densely punctate, and have a vestiture of long, pale setae; and the forewings are pale to whitish, with veins of the membrane colorless to brown (Woodroffe 1953b, Péricart 1999).

Here we report *M. ditomoides* from BC as the first Canadian record for this oxycarenid. Voucher specimens have been deposited in the United States National Museum of Natural History, Smithsonian Institution, Washington, DC (USNM) and University of Georgia Collection of Arthropods, Athens, GA (UGCA).

Specimens examined: CANADA: BC, 100 Ave. nr 140 St., Guildford, Surrey,



Figure 1. *Metopoplax ditomoides* (Costa) ♀, British Columbia, Canada, Blackie Spit, Crescent Beach, Surrey, 28-vi-2011 (E. R. Hoebeke, A. G. Wheeler) [UGCA].

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49°10.994'N 122°50.195'W, 26-vi-2010, 1♀ sweeping forbs; Blackie Spit Park, Crescent Beach, Surrey, 49°03.579'N 122°52.875'W, 24-vi-2011, 26♂, 39♀ & 28-vi-2011, 13♂, 23♀ ex *Achillea millefolium* L., E.R. Hoebeke & A.G. Wheeler.

Adults in BC, including a mating pair, were collected from inflorescences of common yarrow (*A. millefolium*; Asteraceae).

Other forbs growing nearby were goose tongue or salt marsh plantain (*Plantago maritima* L. (Plantaginaceae) and silver burr ragweed (*Ambrosia chamissonis* (Less.) Greene (Asteraceae). The collection of *M. ditomoides* from yarrow at Blackie Spit Park is consistent with the bug's frequent association with composites in the Palearctic Region (Péricart 1999).

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We thank Thomas J. Henry (Systematic Entomology Laboratory, USDA, ARS, Washington, DC) for verifying the identification of *M. ditomoides* and providing the numbers of males and females after

specimens had been deposited in the USNM collection, as well as relevant pages from Péricart (1999), and Joseph V. McHugh (Department of Entomology, University of Georgia, Athens) for providing Fig. 1.

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SCIENTIFIC NOTE

MCOL, frontalin and ethanol: A potential operational trap lure for Douglas-fir beetle in British Columbia**B. Staffan Lingren^{1,2}, Daniel R. Miller³, J. P. LaFontaine⁴**

The Douglas-fir beetle, *Dendroctonus pseudotsugae* (Coleoptera: Curculionidae) is a major pest of Douglas-fir, *Pseudotsuga menziesii* (Mirb.) in British Columbia (Humphreys 1995). An operational trap lure for *D. pseudotsugae* could be useful in an integrated pest management program to minimize mortality of Douglas-fir, particularly in conjunction with anti-aggregation pheromones (Lindgren *et al.* 1988; Ross and Daterman 1995a). The principal pheromone of *D. pseudotsugae* is frontalin (1,5-dimethyl-6,8-dioxabicyclo [3.2.1] octane), which is produced by male and female beetles and attracts both sexes of beetles (Pitman and Vité 1970; Kinzer *et al.* 1971; Rudinsky *et al.* 1976). In British Columbia, *D. pseudotsugae* prefer multiple-funnel traps baited with racemic frontalin (50:50 mix of the two enantiomers) or (S)-(-)-frontalin equally over those baited with (R)-(+)-frontalin (Lindgren 1992).

Two additional pheromones are produced by female *D. pseudotsugae* and attract both sexes of beetles, particularly when presented with host odours or frontalin: MCOL (1-methylcyclohex-2-en-1-ol) (Libbey *et al.* 1983; Lindgren *et al.* 1992; Ross and Daterman 1995b) and seudenol (3-methylcyclohex-2-en-1-ol) (Vité *et al.* 1972; Rudinsky *et al.* 1974; Pitman *et al.* 1975; Ross and Daterman 1995b). These two compounds are isomers of each other.

In 1991, we conducted a trapping experiment in British Columbia, targeting *D. pseudotsugae*. The objective of the experiment was to determine the effect of racemic frontalin and racemic MCOL, alone and in combination, on the attraction of *D. pseudotsugae* to traps baited with ethanol in

British Columbia. Lindgren *et al.* (1992) found that the attraction of beetles to traps baited with the two enantiomers of MCOL seem to be additive with the highest catches in traps baited with racemic MCOL. In laboratory assays, ethanol enhanced the activity of frontalin on arrestment of male *D. pseudotsugae* (Libbey *et al.* 1983). In field assays, ethanol increased catches of beetles in traps baited with frontalin and seudenol (Pitman *et al.* 1975; Ross and Daterman 1995b).

PheroTech Inc. (now Contech, Victoria, BC) supplied all traps and lures. Chemical purities were >95% for all semiochemicals. Release rates were determined gravimetrically at 20–23 °C. Traps were suspended from a metal pole made from electrical conduit tubing such that the bottom of each trap was 0.2–0.5 m above ground level. No trap was suspended within 2 m of any tree. All lures were placed within the funnels (Lindgren 1983).

The experiment was conducted in mature stands of Douglas-fir at three locations in southern British Columbia: 1) Maple Ridge (10 April–12 May 1991); 2) Cache Creek (13–31 May 1991); and 3) Invermere (30 May–8 August 1991). We used 40 12-unit multiple-funnel traps (Lindgren 1983) with dry cups in Maple Ridge and Cache Creek, whereas 20 traps were used in Invermere. Each collecting cup contained a small piece of Vapona No-Pest Strip (Green Cross; Fisons Horticulture, Mississauga, Ontario, Canada) as a killing agent to prevent damage to the target species by predatory insects. At each location, traps were set in blocks of four traps per block resulting in 10, 10, and 5 replicate blocks per location, respectively. Blocks, and traps within

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blocks, were spaced 10–15 m apart in Maple Ridge and Cache Creek and 50m apart in Invermere. Each trap was baited with a white PVC sleeve pouch (40 cm) releasing ethanol at approximately 53 mg/d. Racemic frontalin and racemic MCOL were released from micro-centrifuge tubes (250 µL) and plastic bubblecaps, respectively, each at a rate of approximately 2–3 mg/d. One of the following four treatments was randomly assigned to each trap within a block: (1) untreated control; (2) MCOL; (3) frontalin; and (4) MCOL + frontalin.

Data were analyzed with the SYSTAT (ver. 11) statistical package (SYSTAT Software Inc., Point Richmond, California). Trap catch data were transformed by $\ln(y+1)$ to reduce heteroscedasticity. Data at each location were subjected to ANOVA using the following model: (1) replicate; (2) MCOL; (3) frontalin; and (4) MCOL x frontalin.

Trap catches of *D. pseudotsugae* were significantly affected by MCOL and frontalin at all three locations (Fig. 1). The responses were additive in Maple Ridge and Cache Creek, as there was no significant interaction with MCOL and frontalin at either location (Fig. 1A–B). There was a significant MCOL x frontalin interaction on trap catches in Invermere, resulting in a synergistic effect (Fig. 1C). The difference may be due to the relatively close spacing of treatments in the Maple Ridge and Cache Creek experiments. In contrast to our results, Ross and Daterman (1995b) found that MCOL had no effect on catches of *D. pseudotsugae* in traps baited with ethanol and

frontalin in Oregon. In their study, the combination of ethanol, frontalin, and seudanol was the most effective lure combination for Douglas-fir beetles. Geographic variation in chemical ecology is known for *D. pseudotsugae*, warranting further trials of trap-lure blends over a broader range (Ryker *et al.* 1979; Stock *et al.* 1979; Ross and Daterman 1995b). Nevertheless, traps baited with frontalin, MCOL, and ethanol as described here should be used for trapping

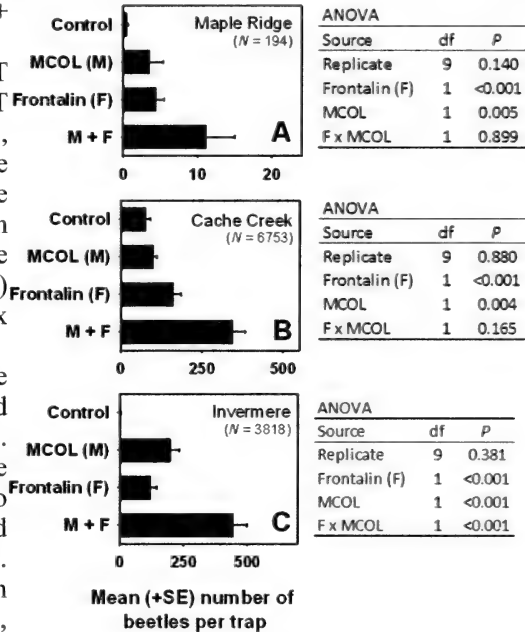


Figure 1. Effect of MCOL and frontalin on catches of *D. pseudotsugae* in traps baited with ethanol in Maple Ridge (A), Cache Creek (B), and Invermere (C). Significance levels (P) for ANOVA on trap catches.

Douglas-fir beetles in British Columbia.

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Symposium Abstracts: Grape IPM

Entomological Society of British Columbia

Annual General Meeting,

Pacific Agri-Food Research Station, Summerland, B.C., Oct. 11-12, 2012

Note: There was a total of eight papers presented in this symposium. We were able to obtain abstracts from six of the authors.

Grape insect pests, including spotted wing drosophila

Susanna Acheampong, *BC Ministry of Agriculture, Kelowna, BC*

Major and secondary insect pests of grapes in the Okanagan Valley, British Columbia, include leafhoppers, climbing cutworms, wasps, grape phylloxera, mealybugs, thrips, mites, and earwigs. Monitoring and management of these insect pests will be discussed. Results from monitoring and damage assessment of spotted wing drosophila in grapes in the Okanagan in 2011 will also be presented. Spotted wing drosophila adults were caught in apple cider vinegar traps placed in vineyards during the last week of July, with peak numbers occurring in September and October. Spotted wing drosophila flies were reared from only damaged wine and table grape varieties sampled, not from intact grape samples. In damaged samples with spotted wing drosophila and other drosophila species, very low numbers of spotted wing drosophila were found compared to other drosophila species.

Cutworm species complex and natural control agents

Naomi DeLury, and Tom Lowery, *Pacific Agri-Food Research Centre, Agriculture and Agri-Food Canada, Summerland, BC*

A total of 27 species of cutworm (Lepidoptera: Noctuidae) were collected as larvae feeding at night on grapevines, *Vitis* sp. L (Vitaceae), in the Okanagan Valley, British Columbia, during April–May, 2004–2012. The majority of the population (86.6%) is represented by three species: *Abagrotis orbis* (Grote), *A. nefascia* (Smith), and *A. reedi* Buckett. The species complex differs by soil type and region, with occasional outbreaks of minor species in specific locations. The invasive lesser underwing moth, *Noctua comes* (Hübner), has potential to cause

significant damage due to increasing numbers and distribution. Natural control agents—parasitoids and pathogens—are being considered for control of cutworm larvae. Twelve species of parasitoids (Hymenoptera and Diptera) have been reared from field-collected late-instar larvae, but parasitism rates are overall very low. Investigation into susceptibility of *A. orbis* to commercial and field-collected fungal cultures, as well as to a novel indigenous *Abagrotis* nuclear polyhedrosis virus, is underway.

Grapevine nematode pests in British Columbia

Tom Forge, Gerry Neilsen, Denise Neilsen, Rosy Smit, and Pat Bowen, *Pacific Agri-Food Research Centre, Agriculture and Agri-Food Canada, Summerland, BC*

Several species of plant-parasitic nematodes are recognized to be damaging pests of grapevines in most major grape-growing regions of the world. These include species of root-knot nematodes (primarily *Meloidogyne incognita* and *M. arenaria*), dagger nematodes (primarily *Xiphinema index*), and root-lesion nematodes (primarily *Pratylenchus vulnus*). In the Okanagan Valley, the northern root-knot nematode, *Meloidogyne hapla*, is present but its pathogenicity to grapevine is not as well known as *M. incognita* and *M. arenaria*. Dagger nematodes in the *X. americanum* group (*X. bricolensis* and *X. pacificum*), are widespread in Okanagan vineyards, but they are not considered to be as directly damaging to grapes as *X. index* is. Species from the *X. americanum* group can be important as vectors of tomato ringspot virus, but only *X. index* transmits grapevine fanleaf virus, which is among the most damaging of grapevine virus diseases. *Pratylenchus penetrans* is also widespread in Okanagan vineyards, but its pathogenicity relative to *P. vulnus* is unknown.

In 2006, we began recovering ring nematodes (*Mesocriconema xenoplax*) from Okanagan vineyards that exhibited patchy, poor growth and impaired root systems. Controlled inoculation studies in field microplots at the Pacific Agri-Food Research Centre–Summerland indicate that *M. xenoplax* can significantly reduce growth (trunk diameter, pruning weights, and root biomass) over three years of self-rooted Merlot. The nematode also reduced trunk growth of Merlot on 3309C rootstock, but Merlot on 44-53 and Riparia Gloire rootstocks appeared to be tolerant to the nematode. Similar microplot research to evaluate the pathogenicity of *P. penetrans* under British Columbia growing conditions is warranted, as is additional research to extend knowledge of the distribution and impacts of *M. xenoplax* on different rootstocks.

Anagrus parasitoids of leafhopper eggs on grapevines

Tom Lowery, *Pacific Agri-Food Research Centre, Agriculture and Agri-Food Canada, Summerland, BC*

There are at least 10 known instances of *Anagrus* (Hymenoptera: Mymaridae) egg parasites successfully imported for the control of leafhopper pests in various countries. In British Columbia, they are important for the control of Virginia creeper leafhopper, *Erythroneura ziczac*, and western grape leafhopper, *E. elegantula*. Their parasitism rates in certain locations near riparian areas reach nearly 100% late in the season. Our research has shown that their activity is limited by a lack of suitable overwintering hosts and that they are sensitive to chemical sprays. Until recently, the taxonomy and host relationships of *Anagrus* species that use eggs of leafhoppers on grapes was poorly studied. A single species, *Anagrus epos*, was thought to parasitize both *E. ziczac* and *E. elegantula*, but it is now understood that one species, *A. daaneii*, uses eggs of the former and a different species, *A. erythroneurae*, parasitizes the latter. A survey is being conducted to determine if a third species, *A. tretiakovae*, that parasitizes eggs of both species has arrived in the province from Washington State, or if it can be imported from its native range in eastern North America.

Vineyard plant diversity: Relation to insect populations

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Ninety-eight vineyards in the Okanagan and Similkameen valleys in south-central British Columbia were included in a study of vegetation within and surrounding vineyards as a component of terroir. Plant species diversity was evaluated three times at the vineyard sites during the 2011 growing season. Attention was paid to broadleaf flowering plants used as cover crops, as these can potentially serve as habitats for beneficial insects. Grapevine-leaf samples were collected during the second and third visits to determine populations of beneficial insects and pests. Fourteen sites were selected for study of native plant communities. These were suitable for vineyard development, but were undeveloped and contained representative native local ecosystems. Hypothetically, inclusion of plants inherent in natural ecosystems as vineyard residents can help to integrate the native and vineyard landscapes, and increase vineyard ecosystem stability by balancing it with the natural environment. The natural and vineyard study sites were mapped, and a database was created using Geographic Information System tools. It was found that, at the majority of vineyard sites where populations of beneficial insects were recorded, at least 10% of the ground-cover crops comprised broadleaf plants at early and mid-season. About 60% of these sites were located in close proximity to the natural areas. It was observed that ground-cover crop composition at some study sites changed considerably during the season, depending on management practices. Some management practices apparently prevented formation of stable habitats for beneficial insects. Plant species diversity in the vineyards was low, consisting of a maximum of two to three introduced species that were evenly distributed. In comparison, the natural sites had a minimum of five plant species observed later in the season. We found higher populations of some beneficial insects when broadleaf flowering plants are resident in vineyard ground-cover crop and when the grapevines are located near natural areas.

Grape-insect toxicology

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The effects of natural and synthetic materials on two insect pests of grapes, cutworms (Lepidoptera: Noctuidae) and leafhoppers (Hemiptera: Cicadellidae), are discussed. In all of these studies assessing the effects of toxicants, the importance of dose response was stressed (Paracelsus: "The dose makes the poison"). In the first set of studies, insecticides were tested for efficacy on fourth-instar larvae of three species of cutworms that have become serious pests in British Columbia vineyards: *Abagrotis orbis*, *A. nefascia*, and *A. reedi*. There was considerable variation in response to these insecticides (chlorantraniliprole [rynaxypyr], permethrin, methoxyfenozide, spinetoram, spinosad, malathion, carbaryl, and *Bacillus thuringiensis*), both within and among the three species. Significant differences in

tolerance among the species to currently registered active ingredients chlorantraniliprole and permethrin illustrates the importance of correct identification of the species complex present in different locations. The second set of experiments examined the effects of essential oils on the Virginia creeper leafhopper, *Erythroneura ziczac*. These studies are an example of experiments that assess behavioral responses, not mortality, resulting from exposure to toxicants. In this case, repellency was measured using leaf-disc choice tests on third-instar nymphs. Of the 11 oils tested, four repelled leafhopper nymphs (paraffin oil, canola oil, mustard seed oil, and lemon oil), whereas tea tree oil and citronella oil repelled nymphs at high concentrations but attracted them at low concentrations. Five materials had no significant effect (eucalyptus oil, peppermint oil, rice bran oil, cedarwood oil, and garlic juice). Essential oils may be useful in reducing leafhopper feeding if appropriate formulations can be developed and effective usage patterns determined.

Presentation Abstracts

Entomological Society of British Columbia Annual General Meeting,

Pacific Agri-Food Research Station, Summerland, B.C., Oct. 11-12, 2012

Current insect pest issues in the Southern Interior of British Columbia

Susanna Acheampong, *BC Ministry of Agriculture, Kelowna, BC*

Insect pests of concern in 2012 on stone fruit and vegetable crops and their management will be discussed. Pest species include San Jose scale, *Quadraspidiotus perniciosus*; apple leaf curling midge, *Dasineura mali*; woolly apple aphid, *Eriosoma lanigerum*; onion maggot, *Delia Antigua*; and, garlic bulb mites.

Micromus variegatus: a new biological control agent for aphids on greenhouse peppers

Rob McGregor, and Jordan Bannerman, *Douglas College, New Westminster, BC*

Brown lacewings (Neuroptera: Hemerobiidae) have rarely been used in augmentative biological control programs. Hemerobiids feed voraciously on aphids in

both the larval and adult stages, and often display low developmental temperature thresholds. Both of these characteristics confer advantages regarding the use of brown lacewings for biological control. Here, we present results of a greenhouse cage experiment where the brown lacewing, *Micromus variegatus*, was released alone and simultaneously with the parasitoid, *Aphidius matricariae*, for management of the green peach aphid, *Myzus persicae*.

Thrips (Thysanoptera: Thripidae): From the greenhouse to the lab, a new pest on lavender, *Lavandula pinnata*, and in coriander, *Coriandrum sativa*, tissue culture
Lauren Erland, Naomi DeLury, and Soheil Mahmoud, *Agriculture & Agri-Food Canada, Summerland BC*

Thrips are a common phytophagous pest with a significant economic impact. Adults and nymphs were found on lavender, a plant

thought to have few or no insect pests, and on coriander in tissue culture. To our knowledge, this is the first report of thrips on *L. pinnata* and of a sterile population of a greenhouse pest in tissue culture.

The confusing transition into adulthood: age–size conflict in insect metamorphosis

Amber Gigi Hoi, Simon P. Zappia, and Bernard D. Roitberg, *Simon Fraser University, Burnaby, BC*

Holometabolous insects often face a trade-off: spending more time as larvae growing for bigger adult size, higher fecundity, but delaying reproduction. We studied such time allocation in larvae under deprived conditions and during a nutrient influx. A waiting tactic was observed and the complex trade-offs involved are discussed.

Cool climate and climbing cutworm: Biological control of a grape pest

T. Scott Johnson, Tom Lowery, Joan Cossentine, and Jenny Cory, *Simon Fraser University, Burnaby, BC and Agriculture & Agri-Food Canada, Summerland, BC*

Abagrotis orbis is a climbing cutworm pest in the vineyards of the Okanagan. Much of their active feeding periods occur under cooler temperatures. We evaluated their susceptibility to several entomopathogenic fungi and nematodes across three temperatures. The larvae were susceptible to entomopathogenic fungi and nematodes with the highest mortality rates occurring at higher temperatures, although mortality occurred at lower temperatures.

Spotted Wing *Drosophila* in fruit crops of interior valleys of British Columbia, 2009 – 2012

Howard Thistlewood, Susanna Acheampong, Charlotte Leaming, Molly Thurston, Brigitte Rozema, Duane Holder, and Gayle Krahn, *Agriculture and Agri-Food Canada, Summerland, BC*

A vinegar fly, Spotted Wing *Drosophila*, *Drosophila suzukii*, was first detected in the British Columbia interior in September 2009, and damaged crops in 2010. We report on its abundance and distribution in traps and plant hosts, on a parasitoid, and other efforts to understand the ecology of this invasive insect.

Effects of thermal stress on survival and development time of *Aphidius matricariae*, a biological control agent of *Myzus persicae*

Christina Hodson, *Simon Fraser University, Burnaby, BC*

We evaluated thermal-tolerance limits of the aphid parasitoid, *Aphidius matricariae*. Heat stress was applied to juvenile parasitoids, and effects on survival and development time were assessed. The results have implications for the effectiveness of *A. matricariae* as a biological control agent during heat waves.

Are fungi and parasitoids compatible for controlling aphids in greenhouses?

Jasmine Norouzi, *Agriculture & Agri-Food Canada, Agassiz, BC*

Beauveria bassiana (strain GHA) in the commercialized form, BotaniGard, affected survival and longevity of a parasitoid, *Aphidius matricariae* attacking *Myzus persicae* on pepper plants, *Capsicum annuum*. The results suggest that the fungus interferes sufficiently with the parasitoids and that it does not have a positive effect on controlling aphids.

Turning up the heat on predation: Temperature fluctuations decrease pest suppression

F. W. Simon, A. M. Chubaty, and B. D. Roitberg, *Simon Fraser University, Burnaby, BC*

Insect activity is temperature mediated, however little work has explored how temperature fluctuations can influence pest suppression. We investigated this phenomenon with a Lotka–Volterra predator–prey model with daily temperature fluctuations. We found that increased amplitude of temperature fluctuations caused large boom–bust cycles, which lead to more severe pest outbreaks.

Visual and olfactory cues used by the apple clearwing moth to locate showy milkweed flowers

Chelsea Eby, *Simon Fraser University, Burnaby, BC*

In British Columbia, adult *Synanthedon myopaeformis* commonly feed on showy milkweed flowers. Vision was examined using ERGs and spectral reflectance. Olfaction was examined using GC-EAD and proboscis-extension assays. A single milkweed floral

semiochemical was shown to be highly attractive in field-trapping assays, whereas visual cues were less important.

***Anagrus* (Hymenoptera: Mymaridae) parasitoids of leafhopper eggs on grapevines**

Tom Lowery, *Agriculture & Agri-Food Canada, Summerland, BC*

There are at least 10 known instances of *Anagrus* (Hymenoptera: Mymaridae) egg parasites successfully imported for the control of leafhopper pests in various countries. In British Columbia, they are important for the control of Virginia creeper leafhopper, *Erythroneura ziczac*, and western grape leafhopper, *E. elegantula*, with parasitism rates in certain locations near riparian areas reaching nearly 100% late in the season. Our research has shown that their activity is limited by a lack of suitable overwintering hosts and that they are sensitive to chemical sprays. Until recently the taxonomy and host relationships of *Anagrus* species utilizing eggs of leafhoppers on grapes was poorly studied. A single species, *Anagrus epos*, was thought to parasitize both *E. ziczac* and *E. elegantula*, but it is now understood that one species *A. daanei* uses eggs of the former, and a different species, *A. erythroneurae*, parasitizes the latter. A survey is currently being conducted to determine if a third species, *A. tretiakovae*, which parasitizes eggs of both species, has arrived in British Columbia from Washington State, or if it can be imported from its native range in eastern North America.

Eocene fossil insect beta diversity, climate, and topography across southern British Columbia and northern Washington

S. Bruce Archibald, David R. Greenwood, and Rolf W. Mathewes, *Simon Fraser University, Burnaby, BC, Royal BC Museum, Victoria, BC, Museum of Comparative Zoology, Cambridge, MA, USA and Brandon University, Brandon, MB*

Just over four decades ago, Janzen hypothesized a relationship between dispersal, topography, climate, and latitude. He proposed that whereas warm valleys and cool mountain passes in seasonal temperate latitudes have a temperature overlap at least part of the year that facilitates dispersal of organisms between valleys, the same elevation difference in the equable tropics share no common temperatures over a year, constituting a physiological dispersal barrier between valleys. This would result in higher overturn of species—increased beta diversity—across tropical montane landscapes. The early Eocene Okanagan Highlands fossil sites of southern BC and northern Washington present a unique opportunity to test this notion independent of latitude. We sampled insect fossils across this 1000-km montane transect of cool mean annual temperatures, yet low temperature seasonality as in the modern tropics. We found that beta diversity was indeed high, supporting Janzen's notion that temperature seasonality is key to montane beta diversity, as well as that global biodiversity was higher in the Eocene than it is today.

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Directors of the Entomological Society of British Columbia, 2012-2013.....	2
J.J. Holland. 'Cosmetic' Pesticides: Safe to Use by Professionals and Homeowners.....	3
G.E. Haas, J.R. Kucera, S.O. MacDonald, and J.A. Cook. First flea (Siphonaptera) records for Kanuti National Wildlife Refuge, Central Alaska.....	6
S. Acheampong, D.R. Gillespie, and D.J.M. Quiring. Survey of parasitoids and hyperparasitoids (Hymenoptera) of the green peach aphid, <i>Myzus persicae</i> and the foxglove aphid, <i>Aulacorthum solani</i> (Hemiptera: Aphididae) in British Columbia.....	12
J.W. Miskelly. Updated checklist of the Orthoptera of British Columbia	24
D.F. Fraser C.R. Copley, E. Elle, and R.A. Cannings. Changes in the Status and Distribution of the Yellow-faced Bumble Bee (<i>Bombus vosnesenskii</i>) in British Columbia.....	31
David R. Horton, Christelle Guédot, and Peter J. Landolt. Identification of feeding stimulants for Pacific coast wireworm by use of a filter paper assay (Coleoptera: Elateridae).....	38
Brittany E. Chubb, Caroline M. Whitehouse, Gary J. R. Judd, Maya L. Evenden. Success of <i>Grapholita molesta</i> (Busck) reared on the diet used for <i>Cydia pomonella</i> L. (Lepidoptera: Tortricidae) sterile insect release.....	48
G. G. E. Scudder. Additional provincial and state records for Heteroptera (Hemitera) in Canada and the United States	56
SCIENTIFIC NOTES	
A.G. Wheeler, JR. and E. Richard Hoebeke. <i>Metopoplax ditomoides</i> (Costa) (Hemiptera: Lygaeoidae: Oxycarenidae): First Canadian Record of a Palearctic Seed Bug.....	57
B. Staffan Lingren, Daniel R. Miller, J. P. LaFontaine. MCOL, frontalinal and ethanol: A potential operational trap lure for Douglas-fir beetle in British Columbia.....	59
ANNUAL GENERAL MEETING ABSTRACTS	
Entomological Society of British Columbia Annual General Meeting Symposium Abstracts: Grape IPM	74
Entomological Society of British Columbia Annual General Meeting Presentation Abstracts	76
NOTICE TO CONTRIBUTORS	Inside Back Cover